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Timed Transfer System Planning, Design and Operation

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October 1981

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16. Abstract

Timed transfer system (TTS) is the type of transit network which consists of a number of "focal points" or transit centers at which transit routes meet. Most or all of these routes operate with the same headways and vehicles come to the centers simultaneously, allowing easy transfer of passengers. Thus transit offers network service instead of individual routes only.

The report gives an overview of different types of public transport services for low density areas and a detailed description of TTS characteristics. A systematic classification of TTS networks and relationships of their operating elements (routes lengths, headways, speeds, numbers of vehicles and others) are presented. Procedure for planning of TTS is followed by a description of information and marketing of such services. The last section demonstrates an application of TTS for improvement of transit services in a suburban area of a large city (Philadelphia).

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Valuable contributions in preparation of the report were made by Joel Gottfried and Maria Lu, research fellows in the Department of Civil and Urban Engineering, University of Pennsylvania.

Personnel from the Southeastern Pennsylvania Transportation Authority were extremely cooperative in providing data and operational experiences needed for the example case presented in section 8.

With the assistance of Mr. Goodman, a full coordination of this research and the studies of other aspects of TTS, performed by Prof. Jerry Schneider's team at the University of Washington in Seattle and Mr. Roy Lave's group at Systan, Inc., in Los Altos, was established. Contacts among these groups insured that the projects were coordinated and complementary. At a meeting of the three principal investigators and several transit operators in Berkeley in July 1980, experiences were exchanged to insure full compatibility between theoretical analyses and their applications for transit systems. At the same time the new name for the studied concept - TIMED TRANSFER SYSTEM or TTS - was adopted.

The authors express their gratitude to all these persons for their cooperation and contributions during this study.

DIMENSION		
SI unit (symbol)	*Conversion factors* (for conversion in the direction of the arrow multiply by the number provided)	*English unit (symbol)*

LENGTH

millimeter (mm)
centimeter (cm)
meter (m)
kilometer (km)

10^3 mm = 10^2 cm = 1 m
10^3 m = 1 km

inch (in., ")
foot (ft, ')
yard (yd)
mile

36 in. = 3 ft = 1 yd
5280 ft = 1760 yd = 1 mile

mm	25.40 / 0.0394	in.
m	0.3048 / 3.281	ft
m	0.9144 / 1.094	yd
km	1.609 / 0.6214	mile

AREA

square millimeter (mm^2)
square centimeter (cm^2)
square meter (m^2)
hectare (ha)
square kilometer (km^2)

10^6 mm^2 = 10^4 cm^2 = 1 m^2
10^6 m^2 = 10^2 ha = 1 km^2

square inch ($in.^2$)
square foot (ft^2)
square yard (yd^2)
acre
square mile ($mile^2$)

1296 $in.^2$ = 9 ft^2 = 1 yd^2
3,097,600 yd^2 = 640 acres = 1 $mile^2$

cm^2	6.452 / 0.1550	$in.^2$
m^2	0.0929 / 10.76	ft^2
m^2	0.8361 / 1.196	yd^2
ha	0.4047 / 2.471	acre
km^2	2.590 / 0.3861	$mile^2$

SPEED

meters/second (m/s)
kilometers/hour (km/h)

1 m/s = 3.6 km/h

feet/second (ft/s)
miles/hour (mph)

88 ft/s = 60 mph (exact)
[1.467 ft/s = 1 mph]

m/s	0.3048 / 3.281	ft/s
km/h	1.609 / 0.6214	mph

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Section 1

TRANSIT SERVICES IN LOW-DENSITY AREAS

One of the basic characteristics of urban areas is that they provide various services superior to those available in rural areas. Urban population generally enjoys publicly provided water supply, sewage disposal, trash collection, various social services, and a number of others. With respect to transportation, urban areas are also superior to rural areas when their population can utilize not only private transportation (automobile, walking, bicycling, etc.) but also public transportation (transit) services. In rural areas the automobile is the basic and often the only means of travel for all except very short distances, where travel on foot or by bicycle is possible.

By its very nature public transportation operates most efficiently where there is certain aggregation of travel demand. Since in low density areas auto ownership is high, demand for travel by transit tends to be very low, so that transit operators find it very difficult to provide an acceptable level of service at a reasonable cost.

This study analyzes various methods of providing transit services in low-density areas. These areas can be classified into two major categories. First, suburban areas of medium and large cities; and second, entire medium and small cities which have low population densities. One of these types of areas is found in most cities.

The focus of this study is the type of transit network and operation in which special transit centers are organized at which vehicles from several different lines converge at the same time, enabling passengers to transfer between any two lines, and then depart in their respective directions. This type of service is called timed transfer system, or TTS. Thus instead of individual transit lines, usually with inconvenient transfers in low density areas, TTS represents a coordinated transit network which passengers can utilize for travel between any two points in the served area with reasonable convenience and average travel speed.

To provide a thorough description and analysis of TTS, and to define precisely its role in urban areas, this study first presents a systematic review of various types of transit services, networks and methods of operation, defining characteristics, advantages and disadvantages of each one. A later part of the report (sections 4 to 7) focuses on the TTS, presenting all its basic elements as well as methodology for their planning and implementation. An example of TTS planning is given in section 8.

1.1 Roles of Transit in Low-Density Areas

Transit services in low-density areas presently tend to be of low quality: they have long headways, often low travel speeds, indirect routing, poor connections among lines, and limited information for passengers. Since such services cannot compete with automobile for most trips, they are mostly used by people who do not have an access to the automobile. However, this condition does not mitigate the fact that for certain segments of the population and for certain types of trips transit is extremely important and plays an integral role in an area's total transportation network; nor should it obscure the fact that it is desirable to shift as much travel from auto to transit as is reasonably possible for various economic, environmental, social and energy conservation reasons.

Transit can have four different roles in low-density areas:

1. To provide the basic mobility for those without access to the automobile. This includes people who do not own an automobile and nondrivers. Although many nondrivers get transportation by being chauffered by the drivers, this population segment is not at all neglibible and when transit service is available and of good quality, it can provide a substantial number of school, shopping and commuting trips for these groups.

2. To provide an alternative service for people who have access to automobiles, but who prefer transit if reasonably competitive levels of service are offered. Most of these passengers are peak hour commuters, but a variety of other travelers and types of trips can also be served by transit.

3. To offer a back-up service for incidental riders at times when auto is not available.

4. To serve as the basic carrier for the entire population during various emergencies, special situations, etc. This type of service is

usually rather expensive to maintain and therefore whenever analyzed on monetary basis, it appears difficult to justify. However, in emergency situations, such as various snow storms, flooding conditions, etc. the value of this service is such that it may easily outweigh very large financial losses at other times.

One aspect of rapidly increasing importance falls into this category of transit role: increasing price and decreasing supply of oil. If our country one day faces a real energy crisis, the role of transit will rapidly and drastically increase. Since it is not easy to increase transit capacity in a short period of time, maintaining the back-up transit service and its organization for expansion is presently of a great and further increasing importance.

The second role -- to serve as an alternate mode, particularly for peak hour commuters -- is usually the dominant one. In some areas service is provided only during the peak hours. This service does not meet the needs of the first role -- to provide basic mobility to those who do not have an automobile available, nor does it serve as an alternative for any "choice" riders. Captive transit riders therefore have extremely restricted mobility during most periods of the day. Even the services operated throughout the day offer only a limited mobility for other than work trips because of their radial orientation toward central cities. Only large cities have reasonably good circumferential and "crosstown" services.

1.2 Present Types of Transit Services

Transit operators can offer several different modes and types of operation for services in low density areas. The particular service being offered depends on local conditions such as ridership patterns, land use, available infrastructure, population densities, and financing. Each of the services described below has its appropriate range of application. Transit officials should have a complete understanding of the characteristics and applications of these services in order to insure efficient operations in each particular area.

1.2.1 Semipublic Paratransit. This term refers to carpools and vanpools, i.e. the services which are available and adjusted to the needs of a limited number of subscribers, mostly on a regular basis (commuting). Each trip usually follows the same fixed route and schedule every day and it is

available to a group of riders from a company, neighborhood, or some other organization, but not to the general public. The major objective of semipublic paratransit is to increase efficiency of private automobile, van or bus trips by raising their average vehicle occupancy rates, thus reducing the number of vehicles traveling between common origins and destinations. The most common paratransit modes, carpools and vanpools, comprise, together with buses, high-occupancy vehicles (HOV).

Car- and vanpools are usually organized by private individuals or employers. However, in many cases a public agency gathers a list of persons with common origins and destinations and assigns them to a vehicle operated by an individual who has expressed a willingness to drive the vehicle. The primary function of the public agency is to serve as an information gathering service which enables all potential participants to find out about other travelers with whom they can travel.

The major advantage of these modes is their ability to provide direct service at a cost lower than that of private auto (particularly if the social benefits, such as reduced traffic volumes, air pollution, energy consumption and parking area requirements are included). Because each vehicle serves a small group of riders (carpools carry 2 to 6, vanpools 7 to 15 persons), it can travel directly to a user's home and reach users who may not be near a transit route. This main advantage of semipublic paratransit is that the small transportation units which are utilized enable this mode to economically serve some areas which have population densities too low for efficient service by regular transit and by the modes using larger vehicles. Another advantage is that semipublic paratransit involves very low direct investment in infrastructure.

Several features of these modes, however, limit their widespread application and their utility. The most important is their inability to meet full transportation needs of any person, including their users for work trips. To organize carpool or vanpool trips it is necessary to have the following conditions:

1. A group of workers from an office or company must live within the same general area.

2. Starting and closing times at the workplace must be fairly uniform. This restricts most vanpooling to peak hours, or other shift changes.

Consequently, semipublic paratransit is primarily applicable to large offices, factories or downtowns. If the concentations are not large enough, the result will be a service which involves circuitous routing and not enough riders per vehicle for an efficient operation. Even if the conditions are met, the scheduling inflexibility limits the utility of these modes for the public. Since there is only one trip per day, the user has no chance to alter his/her schedule. This differs from regular transit where there is the ability to choose a variety of travel times, or the private automobile, which may be available at all times.

If a public agency is involved in encouraging semipublic paratransit services, it must be certain that existing public transportation services are not being duplicated, thus creating an inefficient competitive network. Also, if a large enough volume of riders are observed to be using this form of transportation, it may indicate a need for a public transportation route with higher capacity or improved level of service. Suscription bus can be used as a "transitional" mode between semipublic paratransit and transit.

In summary, semipublic paratransit services have applications for a certain portion of worktrips, but cannot be relied upon as the principal public transport service in any given area. Other services and modes are required for off-peak, shopping, social, commercial and the remainder of worktrips.

1.2.2. Public Paratransit. This category of modes represents for-hire common carrier transit available to the general public. Modes which provide these services are the taxi, dial-a-ride and, to a limited extent in some cities, jitneys.

Taxi service is tailored entirely to the user's desire. This makes it applicable to many of the dispersed trips which can occur in low density areas. However, taxi service can never have more than a limited role in meeting the transportation needs of low density areas for the following reasons:

1. Supply of taxi service in these areas is usually very poor (slow and unreliable). Taxi operators find it more profitable to work in towns or cities where demand for their service is greater due to the larger density of travel.

2. The individualized service provided in small vehicles results in relatively low labor productivity and high charges to the user. Thus, taxis

generally involve by far the greatest out-of-pocket expense to users of all modes.

Dial-a-ride or dial-a-bus consists of minibuses or vans directed from a central dispatching office. Passengers call the office and give their origin, destination and desired time of travel. The office plans bus routings so that each trip serves as many passengers as possible.

The objective of dial-a-ride is to provide a flexible, "demand responsive" system similar to taxi service, but with higher average vehicle occupancy rates, which makes it possible to charge lower fares. Meeting this objective could make dial-a-ride suited to many transit applications in low density areas where trips are widely dispersed, and in areas which have population densities too low for frequent regular transit service.

Dial-a-ride is a relatively new concept first implemented in the early 1970s. Cities which have used dial-a-ride include Haddonfield, NJ; Ann Arbor, MI; Batavia, NY; Emmen, The Netherlands; and Hannover, W. Germany. Although operational experience has been varied, the results indicate that it is very difficult to group a large number of riders in vehicles. This is due to the lack of concentration of demand for similar trips during a given time period. If the service attempts to handle diverse demands in one trip, the result is circuitous routing and longer travel times which discourage ridership. In addition, due to the absence of fixed routes dial-a-ride has weak identity, which further inhibits potential ridership. The overall result is that dial-a-ride often requires a very high subsidy per unit (passenger or passenger-km).

The subsidy generally decreases with increasing vehicle occupancy. When vehicle occupancy reaches consistently high levels, this often indicates that there is enough demand to justify implementation of a regular public transit bus route. Therefore, conditions which are conducive to the use of dial-a-ride appear to be rather limited in most areas.

Jitney services are used extensively in the countries with low-cost labor. In the developed countries they are rarely operated, mainly because they are suited to heavily travelled routes on which regular transit buses can provide similar service at lower cost due to the higher labor productivity (space- or vehicle-km per driver-hour). In any case the jitney mode does not apply to low density areas since it requires heavy demand along at least substantial portions of its routes.

1.2.3 Conventional Transit. Most transit services in low density areas are provided by buses; in a few cities rail transit also penetrates and serves these areas, usually as a regional system.

Transit networks typically consist of major trunk routes following radial directions to/from center city, supplemented by numerous feeders or branches going from the radials into various directions. Other routes may be circumferential, crosstown, or with irregular geometric form.

Radial lines with their branches and feeders primarily serve the trips to/from central city and they often have heavy peak hour patronage. During off-peak periods passenger volumes are often sufficient to justify reasonably short headways (in the order of 10 to 20 minutes). These lines are usually operated by standard 33- to 40-ft long buses with capacities of 35 to 53 seats.

In most cities with rail transit (light rail, rapid transit and regional rail) some of these lines penetrate suburban areas and serve radial directions. These modes are found in some 15 cities in the United States and Canada, with another half-a-dozen cities having such lines under construction.

Although radial routes, regardless of technology (bus or rail), do not always provide extensive area coverage or direct connections for intrasuburban travel, they can be significant elements of transit services for these trips in two ways:

1. They can offer service among many points along their routes. Since they usually offer rather high speed and frequency of service along busy corridors, they can attract a substantial number of such trips. Presently this potential is underutilized in most cities due to inadequate integration of network services, express runs which are convenient for CBD-oriented trips only, and a lack of information, marketing and other supporting activities.

2. Major bus and rail stations, particularly terminals, can often be very effectively utilized as transit centers for timed transfer systems.

Circumferential, crosstown and various irregular lines usually serve trips among various points within low density areas. They are served by standard buses or by minibuses with seating capacities of 15 to 25 seats. These lines usually have rather low patronage and therefore operate with long headways (from 15 min. up).

In comparison with various types of paratransit and commuter transit modes, regular (conventional) transit has a major advantage: it offers fixed, predictable service along known routes throughout the day. It can therefore serve all people who travel within its service area at any time of day. On the negative side, fixed transit routes with service at long irregular headways and with inconvenient transfers among routes is often inferior in speed and convenience to some demand-responsive paratransit services which involve no transfers. Moreover, regular transit may cover less of its operating costs due to low load factors typical for low density areas.

1.3 Problems of Public Transportation in Low-Density Areas

The preceding review of modes and types of services presently utilized in low-density areas shows that these services are in most cases rather deficient. Paratransit can serve only a fraction of trips. Regular transit, as presently operated, is available to the public, but offers limited area coverage, infrequent service, usually with irregular schedules and uncoordinated transfers. As a result, transit is usually inconvenient to use for many trips, particularly if traveler's origin and destination do not coincide with a transit line: transfers without physical closeness and schedule coordination represent an unacceptable inconvenience.

The basic problem in providing high quality transit services in low-density areas is that the low ridership makes an improved service (higher network density, service frequency, etc.) difficult to economically justify: subsidies per passenger are usually considerably higher than in inner city areas (which, incidentally, tend to have population with lower average incomes than low density suburban areas).

There are several causes for these problems, some of which can be corrected by changing policies of development or adaptation of existing facilities. Other causes can be greatly alleviated by changes in transit service organization described later in this report.

The problem of generating enough riders to sustain an acceptable service frequency is related to land use planning in many suburban areas of the United States. The provision of transit service was not considered as a factor in most suburban developments. These areas were expected to be completely served by the automobile. The problems caused by lack of public transport

services were not recognized for many years. This attitude led to extremely spread out residential areas whose transportation patterns are characterized by dispersed origins and dispersed destinations. Improved coordination of land use with transportation planning can reduce this problem in future urban development.

The spread out residential patterns reduce the population which can be effectively served by a given transit route. In general, people will not walk more than ¼ mile (5 minutes) to a transit stop. Lower population densities mean that there are less potential riders in the served area of any route. With time, potential riders who are close to a transit route have decreased their transit riding habit to a much lower level than those in more densely populated areas. The low residential densities and dispersed transportation patterns make it necessary for households to own often more than one automobile per family, presenting a great competitive obstacle to transit.

Another important consideration is that the dispersed nature of transportation patterns characterized by many origins and many destinations makes it very difficult to provide bus routes which enable reasonably direct transit services for point to point travel. In some cases there may be large traffic generating points such as a local downtown area, a regional rail station or a shopping center, but travel to these points still involves a low proportion of the area's total trips. Therefore, transit riding in these areas usually requires a network of routes with easy transferring among them. Presently low service frequency on individual routes with uncoordinated transfers results in extremely long waiting times for using more than one route. This eliminates a large segment of potential riders.

The third factor which makes it difficult to provide adequate levels of transit service is that the physical and geometric layout of streets and residential developments are often incompatible with transit service. Residential streets tend to have circuitous routing rather than the grid or radial network forms of more densely populated areas. This causes bus routes to be aligned in a very inefficient pattern with slow operating speeds and circuitous routing. The physical layout of major roads and highways often lacks adequate space for pedestrians or transit riders: sidewalks are narrow if they exist at all, space for waiting at bus stops is limited, and there

are few signalized intersections which provide a safe pedestrian crosswalk. Therefore, many potential riders will not ride transit because of the risk and inconvenience involved in reaching the bus stop.

Little can be done about past land use planning decisions, but many other factors are within control of local officials. Relatively minor modifications in street and intersection design can often bring major improvements for transit users by facilitating their walking and waiting at transit stops. However, the most effective increase in level of transit service and its competitiveness with auto can be achieved in many areas with rather small effort by adoption of timed transfer systems. This form of transit service changes individual lines into an integrated network which can attract a significantly higher ridership than is presently the case in most low density areas.

Section 2

TRANSIT NETWORKS: TYPES, CHARACTERISTICS AND ELEMENTS

Transit network forms, which can be classified into several general types, depend on street networks, urban form (land use patterns, densities, etc.), topography, and a number of other factors. Despite the many specific features that each network has, certain types of network form have distinct service/operational characteristics. These are briefly described here.

2.1 Network Types

Grid network, found in many cities with rectangular street patterns, consists of lines laid out in a rectangular pattern, with numerous transfer possibilities at intersecting points. It thus has an extensive and even area coverage, and offers a high connectivity. It does not have the problem of excessive convergence and concentration of routes, sometimes characteristic of radial networks. It is simple for passenger orientation, but it does not always follow major travel desire lines. Many trips follow a somewhat circuitous "L" configuration.

Grid networks are well-suited to evenly populated areas with grid street patterns, which require rather uniform quality of transit service. Examples of these networks are found in many parts of New York City (buses), Philadelphia (buses, trolleybuses, streetcars), Los Angeles (buses), Toronto (all modes, including buses, trolleybuses, streetcars and rapid transit), and Osaka (rapid transit).

A schematic grid transit network is shown in Fig. 2.1.

Radial network consists predominantly of radial or diametrical routes, with the focus on city center (CBD), or on a suburban major activity center (MAC). Thus it tends to follow the heaviest desire lines "radiating" from the focal point in several directions and splitting into many branches with lower service intensity toward lower density suburban areas. Route duplication in the central area provides adequate capacity for handling of the most concentrated travel volumes on these network sections.

In planning and scheduling of branch lines, regularity of service on the joint sections must be carefully analyzed to prevent pairing of vehicles, when one delayed overloaded vehicle is followed immediately by a lightly loaded

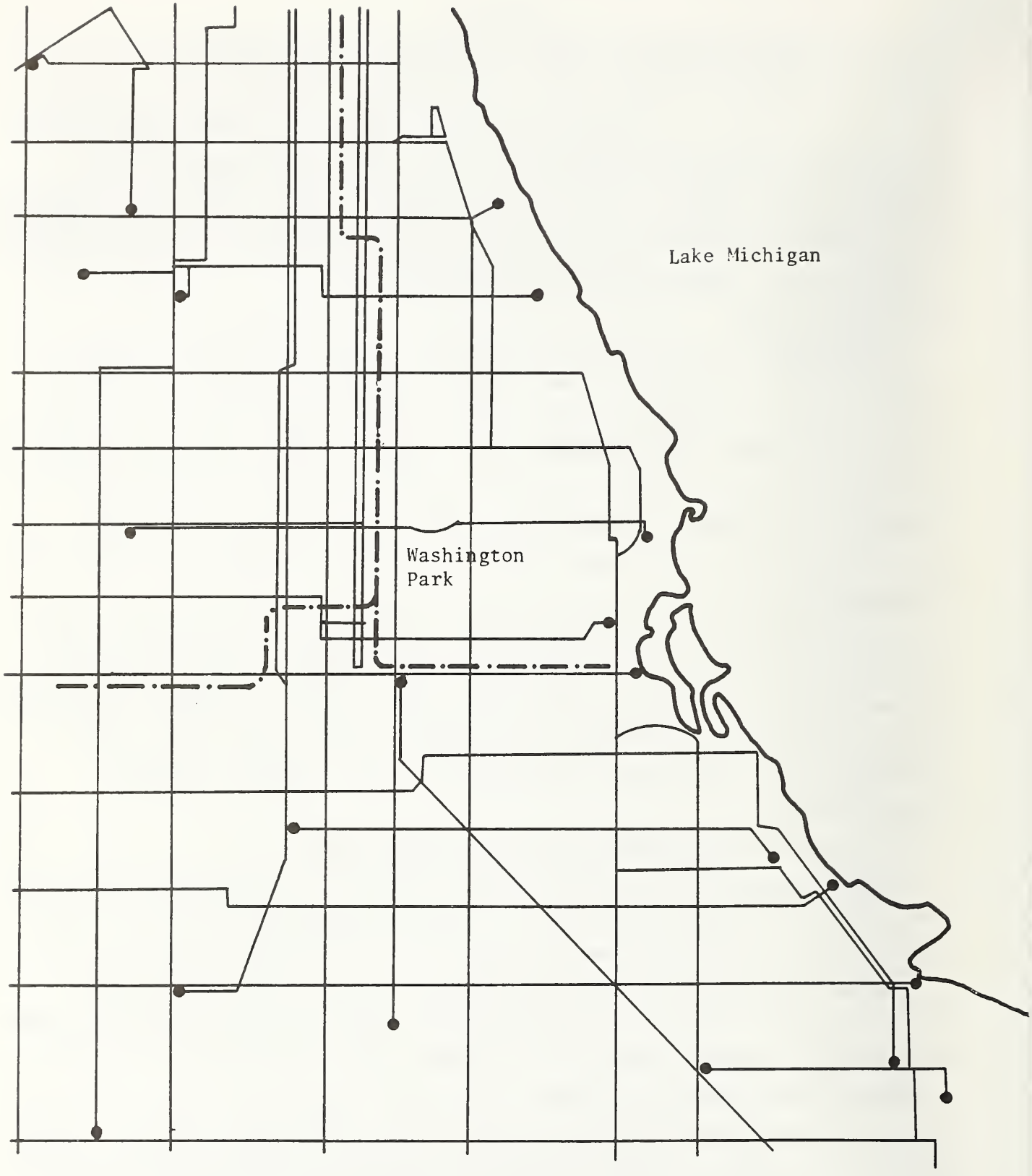


Figure 2.1 Grid-type transit network (routes in a section of Chicago)

vehicle. This problem may be particularly acute during the peak hours.

Radial network has a lower connectivity than grid. Usually circumferential routes must be provided to allow more direct travel for non-radial trips.

Since the area coverage and service intensity of the radial network are uneven - decreasing from the center outward - this type of network is best suited to concentrated cities with radial street network. Most regional rail transit networks (e.g. Philadelphia, Chicago, Boston) have this form, but other modes also follow it in many cities.

Figure 2.2 shows a typical radial transit network.

Irregular network type includes all networks which do not follow any geometric pattern. They are found in many cities with irregular street patterns, various topographic barriers, and other influencing local conditions. No general characteristic about area coverage, connectivity, directness of travel, etc. can be made about irregular networks since they all vary among different cases.

Irregular transit networks are found in some older cities with irregular street patterns (Boston), but also in most recently built suburban areas where residential areas have been designed with street networks very poorly suited to transit services.

An irregular transit network is shown in Fig. 2.3.

Flexible transit routings followed by dial-a-ride and several other types of paratransit services are usually determined by passenger demand - individuals or groups. These services can be classified into three different types:

- Many-to-one (or one-to-many), shown in Fig. 2.4(a), are often used for feeder services to major radial routes. An example is dial-a-ride service in Bay Ridges, Ontario.

- Many-to-few [Fig. 2.4(b)] are used in areas with several focal points (stations, suburban MACs, etc.) surrounded by low-density areas. Examples are dial-a-ride services in Regina, Saskachewan, Ann Arbor, MI, and Emmen, The Netherlands.

- Many-to-many [Fig. 2.4(c)] is the pattern for serving low density areas without any focal points. Batavia, NY has this type of service.

Timed transfer system network has, by definition, focal points and fixed route links among them (Fig. 2.5). Distances among the focal points are rather uniform, except if operating speeds on them vary; in that case link lengths tend to increase with speeds. This network type will be discussed in detail in later sections of this report.

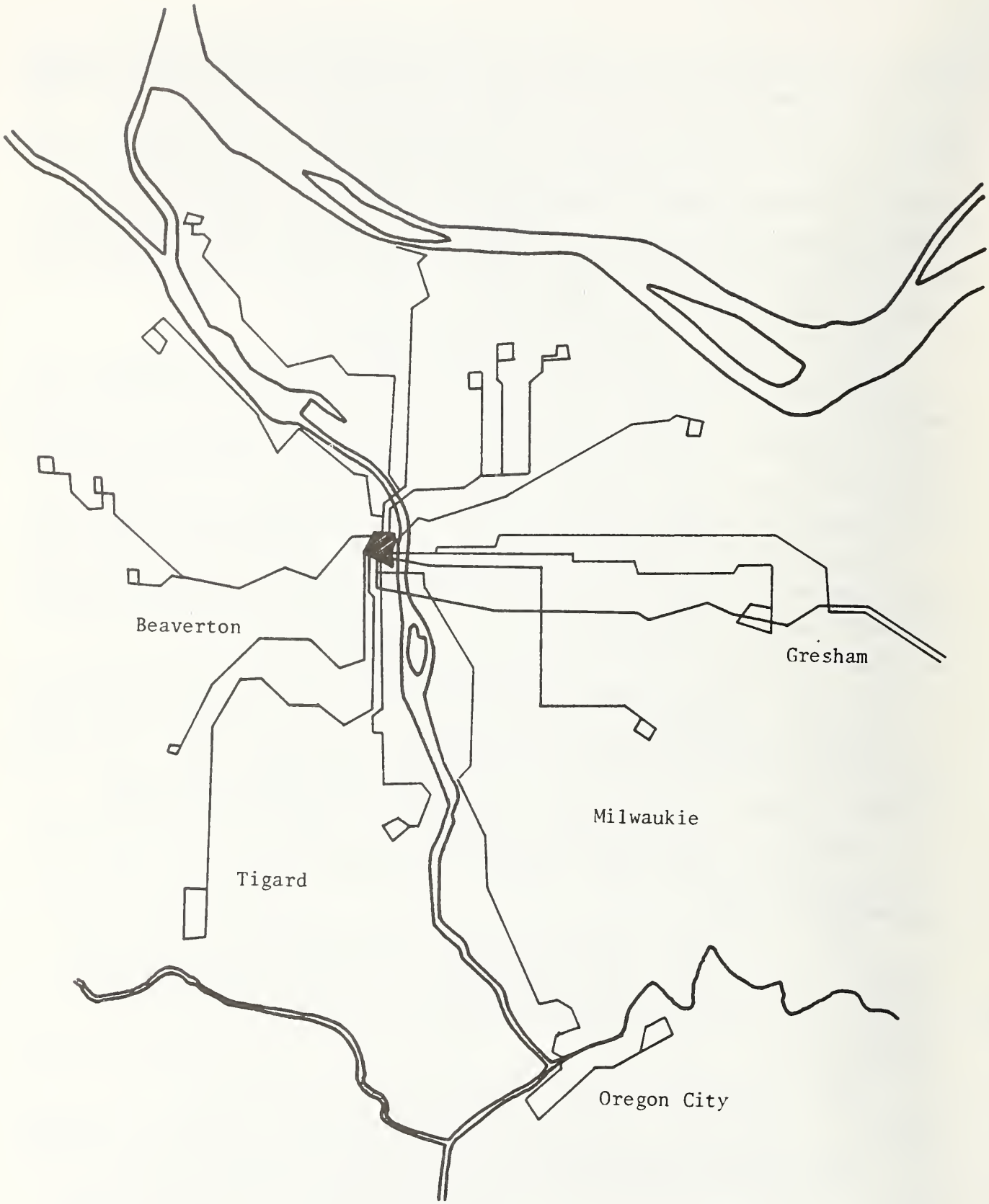


Figure 2.2 Radial-type transit network (selected routes in Portland, OR)

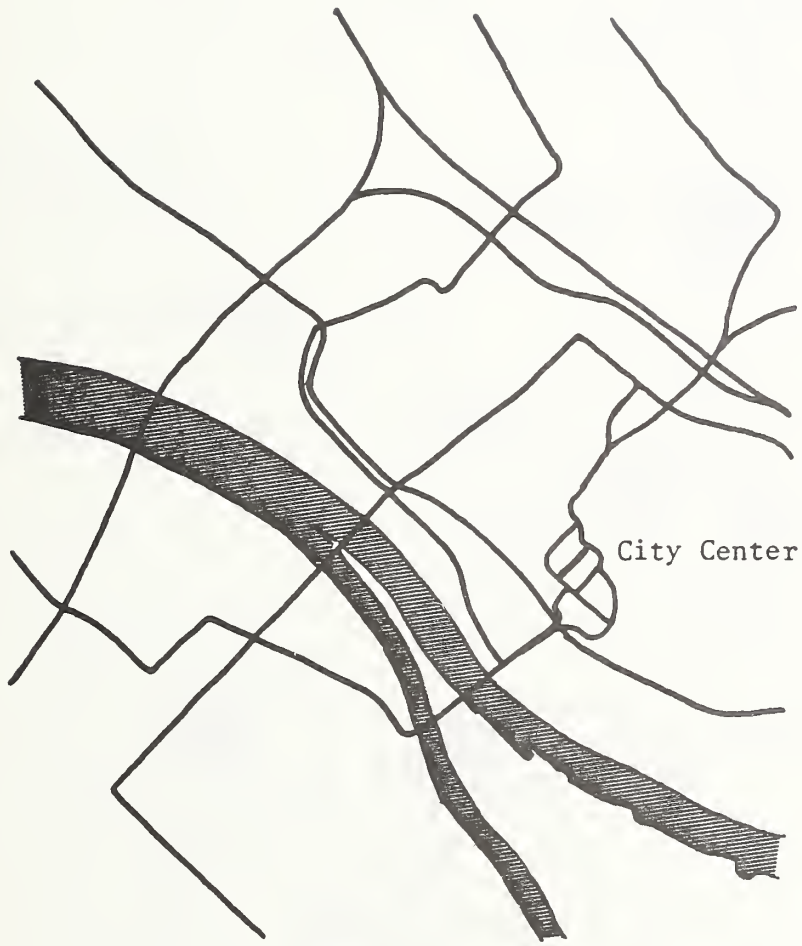
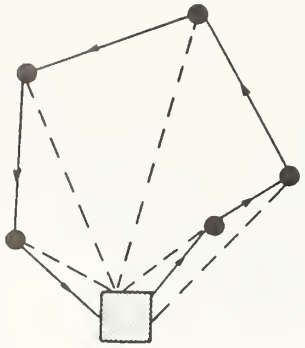
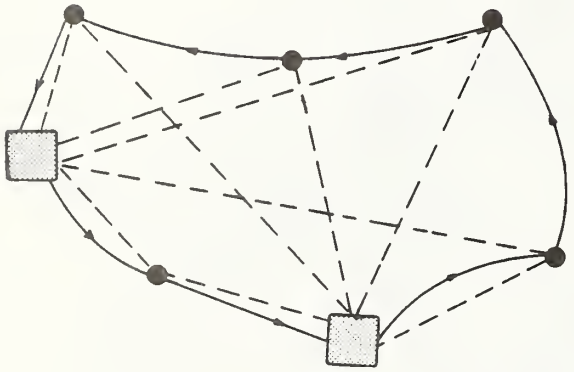


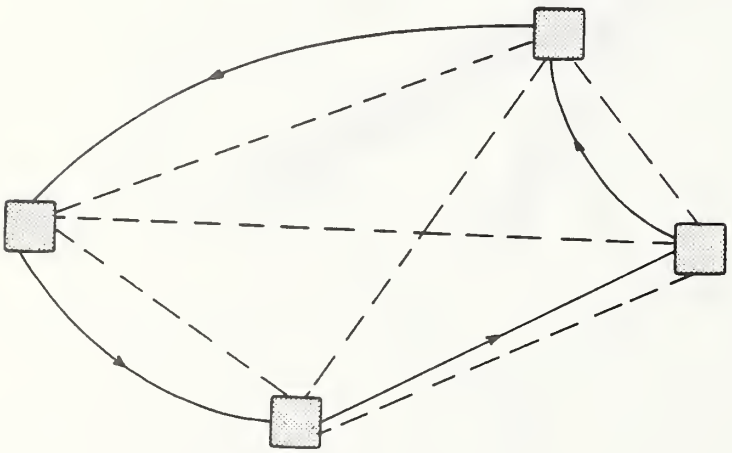
Figure 2.3 Irregular-type transit network (selected routes in Bremen, W. Germany)



(a) Many-to-one



(b) Many-to-few



(c) Many-to-many

Figure 2.4 Different types of flexible transit networks

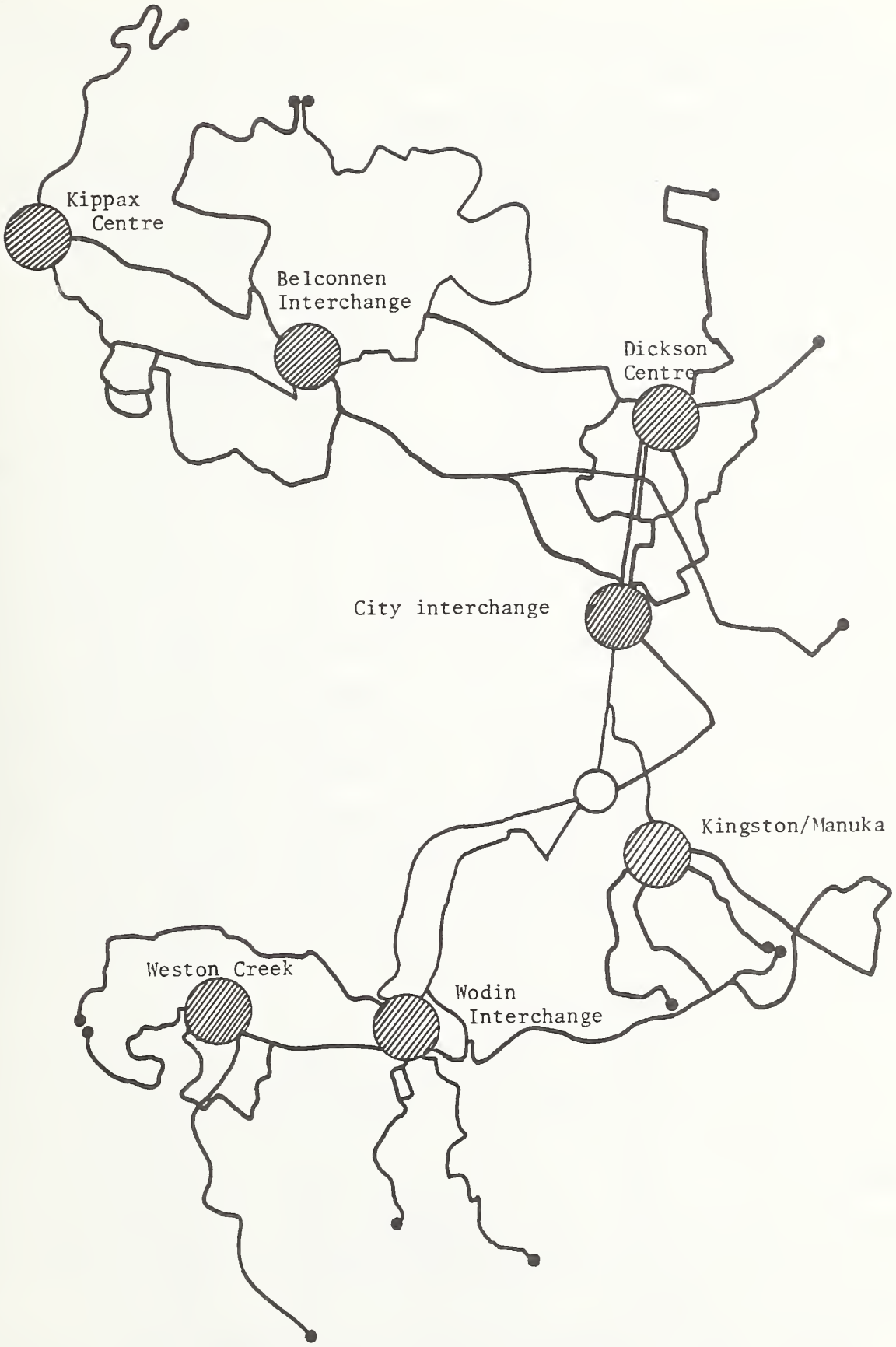


Figure 2.5 Timed transfer system network (selected routes from Canberra, Australia)

A summary of characteristics of different network types is presented in tabular form in Table 2.1.

2.2 Network Characteristics and Elements

Performance and efficiency of transit networks and service can be measured by several characteristics which affect one or more of the three major concerned parties: passengers (P), transit operator (T) and community or city (C). The characteristics and the parties they affect most directly are:

- Area coverage (P,C)
- Directness of service (P)
- Connectivity (P)
- Density of service (P,C)
- Speed (P,T,C)
- Infrastructure (T)
- Operating costs (T,C).

Each one of these characteristics will be defined and briefly discussed here.

Area coverage expresses the extent of a network in an area. It is defined as the percentage of total legally defined transit service area (e.g. city or county) within a specified walking distance of all transit stops and stations. This area, within 5-minute walking distance (about 1/4 mile or 400 meters) from all transit stops can be defined as the primary service area. Points between 5- and 10-minute walking distance (respectively 1/4 and 1/2 mile, or 400 and 800 meters) represent the secondary service area from which a smaller portion of potential riders are attracted. Thus definition of area coverage is based on walking access, which is always used in central cities. In low density areas where transit can rely on several different feeder modes, this standard applies only to the portion of users who walk. For access by automobile (e.g., park-and-ride, kiss-and-ride), service area is much greater and cannot be explicitly defined. The "drawing area" by bicycle is by its size between the drawing areas for walking and auto access.

A substantial portion of the trips which have origin and destination within a 5-minute walk of transit stops can be expected to be attracted by the transit service, provided it is of satisfactory quality. Beyond the primary service area, the percentage of trips served by transit drops off gradually, as illustrated in Fig. 2.6, due to the unwillingness of people to walk longer distances. The curve plotted in the figure is of general form; its actual shape depends on the type and quality of transit service, quality of competing services, and various local factors.

Another important measure of transit service extensiveness is the percentage of population living within the primary and secondary service areas. In cases where there are two networks which offer different levels of service (such as

Table 2.1 Summary of characteristics of different network types

Network type / Characteristic	Grid	Radial/ circumferential	Irregular	Flexible	TTS
Area coverage	Very good	Good in central area, decreasing outward	Variable	Ubiquitous but unstable	Variable
Directness of travel	Poor	Good for radial, poor for many others	Variable	Usually good	Variable
Transfers: convenience and delay	For most trips one	For most trips none	Very poor	Poor	Excellent
Service quality	Uniform	Excellent for radials, lower for other directions	Uneven	Personalized - varies	Very good
Network clarity and image	Excellent	Very good	Poor	Very poor	Very good

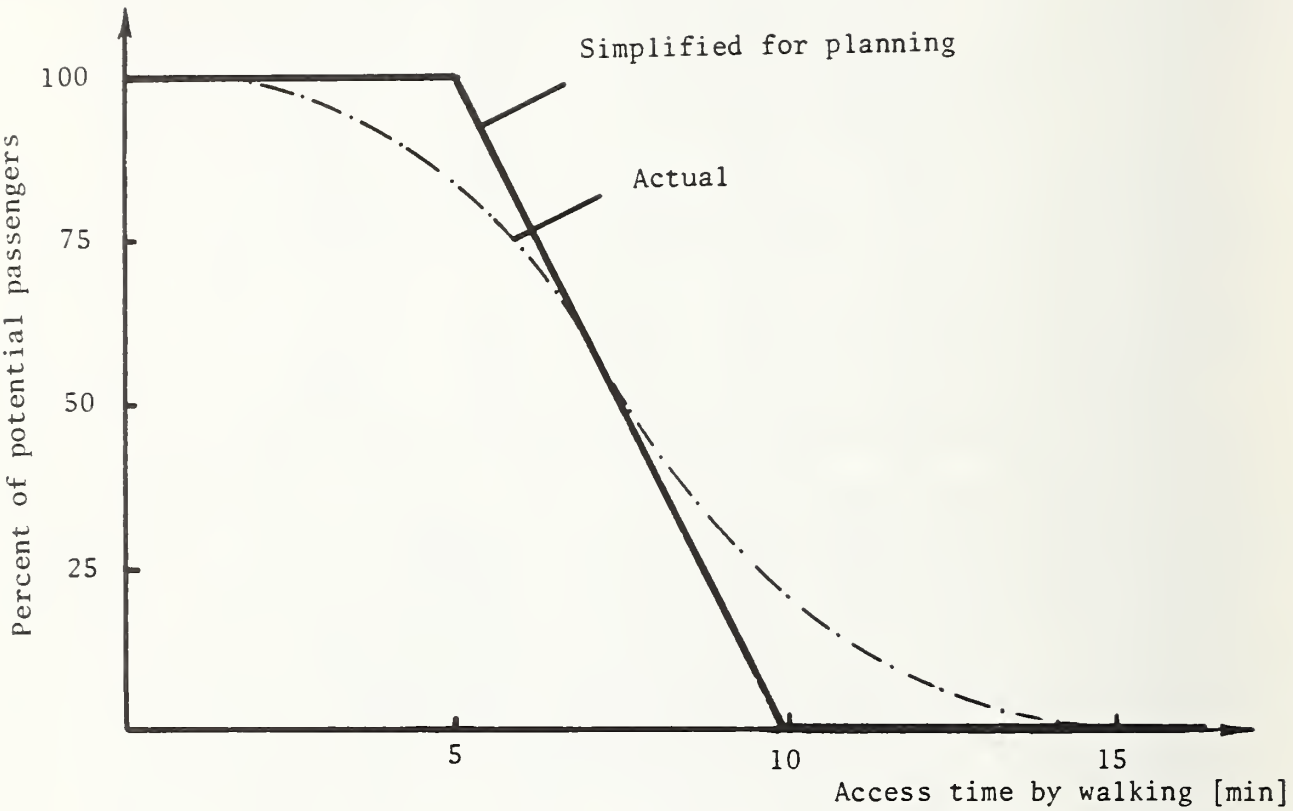


Figure 2.6. Percent of potential transit passengers using transit as a function of walking access time.

local and express service or bus and rapid transit) area coverage may be considered separately for each one, since each service attracts different users or different trips of the same users. A graphical representation of area coverage by transit network in a city is given in Fig. 2.7.

To provide a good transit service, in an area, very high area coverage must be achieved so that most points, and particularly all major traffic generators, are accessible by transit. Since every increment in area coverage involves additional costs, transit networks represent a compromise between costs and area local factors such as land use, residental densities, street patterns, economic factors, etc.

Directness of service is defined as the ratio of the straight line distance between two points to the distance between those two points via the transit network, following the most convenient routing. The ratio should be as high as possible, since direct transit service results in shorter travel times. Also, passengers have great psychological resistance to traveling in a circuitous, indirect manner.

In some situations, circuitous routings are adopted in order to provide better area coverage. This occurs most frequently in low density areas where demand for transit is low. When circuitous routes are necessary, it is desirable that their greatest circuity occurs on the outlying sections of the route, so that the least number of riders are negatively affected.

Connectivity is expressed by the percent of trips which can be made without transfers. It depends on the pattern of travel and transit network layout, and on the relationship between routes and lines. To explain this, the terms transit route and transit line must be defined.

Transit route is a set of streets which a group of vehicles follow in their service between two terminal points. Transit lines are found on all streets on which transit service of one or several routes exists. In other words, route length of a network is a sum of all route lengths, while line length is the total length of all streets on which transit routes operate. Route length can therefore be equal to, or greater than, line length.

Figure 2.8 shows a transit network operated in two different manners. In case (a) only two routes are operated; in case (b) four routes serve the same streets. Line lengths are the same for the two systems, while route length in case (b) is twice greater than in case (a). For a given (fixed) travel demand frequency on each route in case (a) should be two times greater than in case (b),

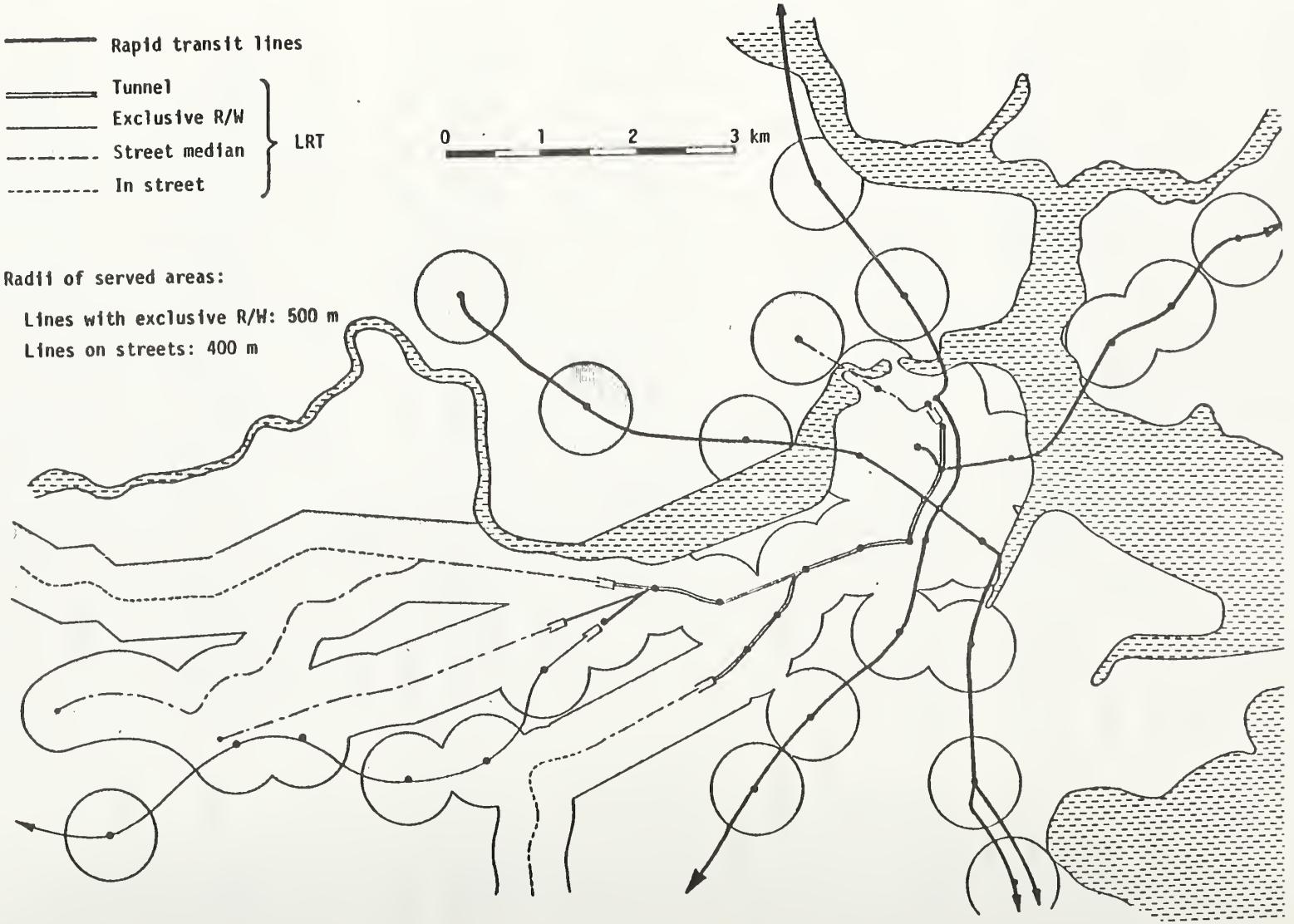
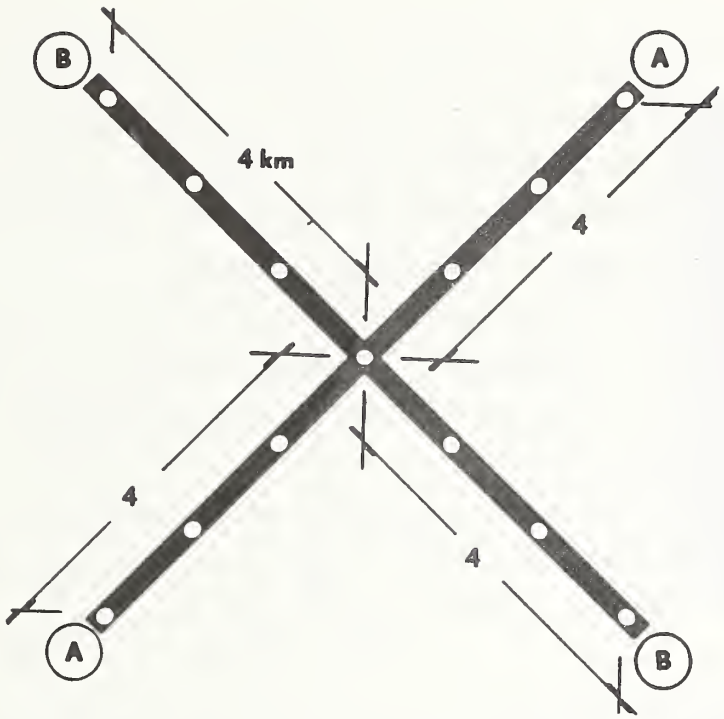
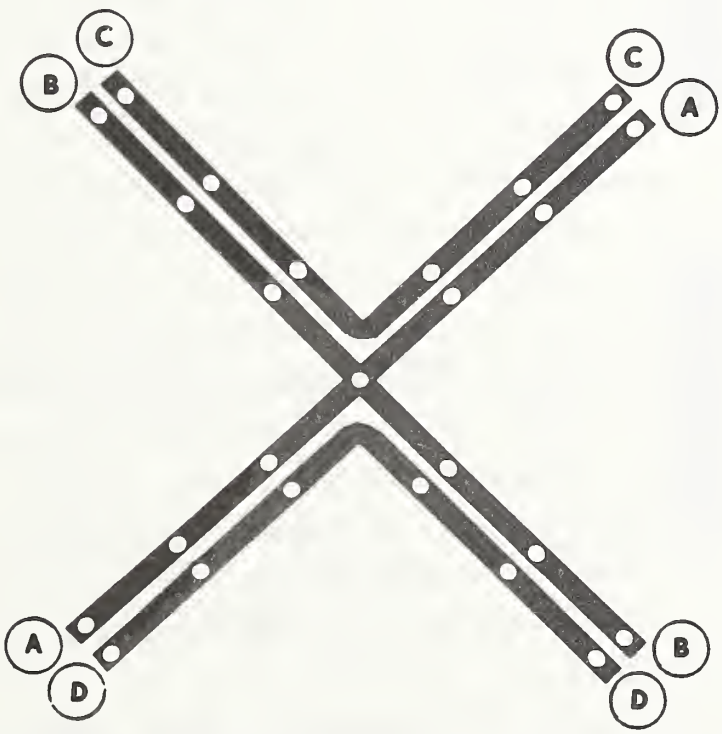


Figure 4. Rail transit lines in Boston and their service areas



(a) Independent route operation: two routes, total route length = line length = 16 km.



(b) Interconnected route operation: four routes, total route length = 32 km, line length = 16 km.

Figure 2.8 Concepts of transit route lengths and line lengths

while frequency on all lines is the same. Number of transfers in case (b) would be considerably smaller than in case (a). Therefore network (a) would have a lower connectivity, but higher service frequency on routes than network (b). The former would involve more transferring, but shorter waiting for the first vehicle than the latter.

Degree of connectivity in a transit network can also be expressed by its ratio of route length to line length. This ratio expresses the system (supply side) characteristic, while percent of trips involving transfers reflects also usage (demand side) characteristics.

Density of service is closely related to area coverage. It describes how intensively an area is served by transit. It can be measured by several indicators such as line length, route length or vehicle-km/hour provided per unit of the served area.

Density of transit networks, i.e., line kilometers per square kilometer of area, is usually determined as a compromise between network extensiveness (coverage) and frequency of service. For example, the lines shown in Figure 2.9 serve a corridor with a width W which has a demand for F transit vehicles/hour. Service can be provided in several different ways. In the first case (A) one line is provided; the maximum walking distance to the line from any point within the corridor is W/2, while the average walking distance is W/4, assuming a uniform population density across the corridor. Frequency of service on the line is F. In the second case, (B), two lines are provided, each with frequency F/2. Here, the maximum walking distance is W/4, and the average is W/8. Finally, if three lines are provided, as in case (C), a frequency of only F/3 vehicles per hour is offered on each line, but the maximum walking distance is decreased to W/6, and the average to W/12. The trade-off between access (walking) distance and waiting time in selecting network density is obvious here.

Speed of transit services is one of the basic elements determining their level of service with respect to passengers, and thereby attraction of passengers, as well as operating cost, affecting the operator and, indirectly, the city which often contributes financial resources.

Passengers are affected by the operating or travel speed V_o, or the average speed of transit vehicles along a route between the two terminals. If route length is L [km] and travel time between terminals T_t [min], operating speed is:

$$V_o[\text{km/h}] = \frac{60L}{T_t} . \qquad (2.1)$$

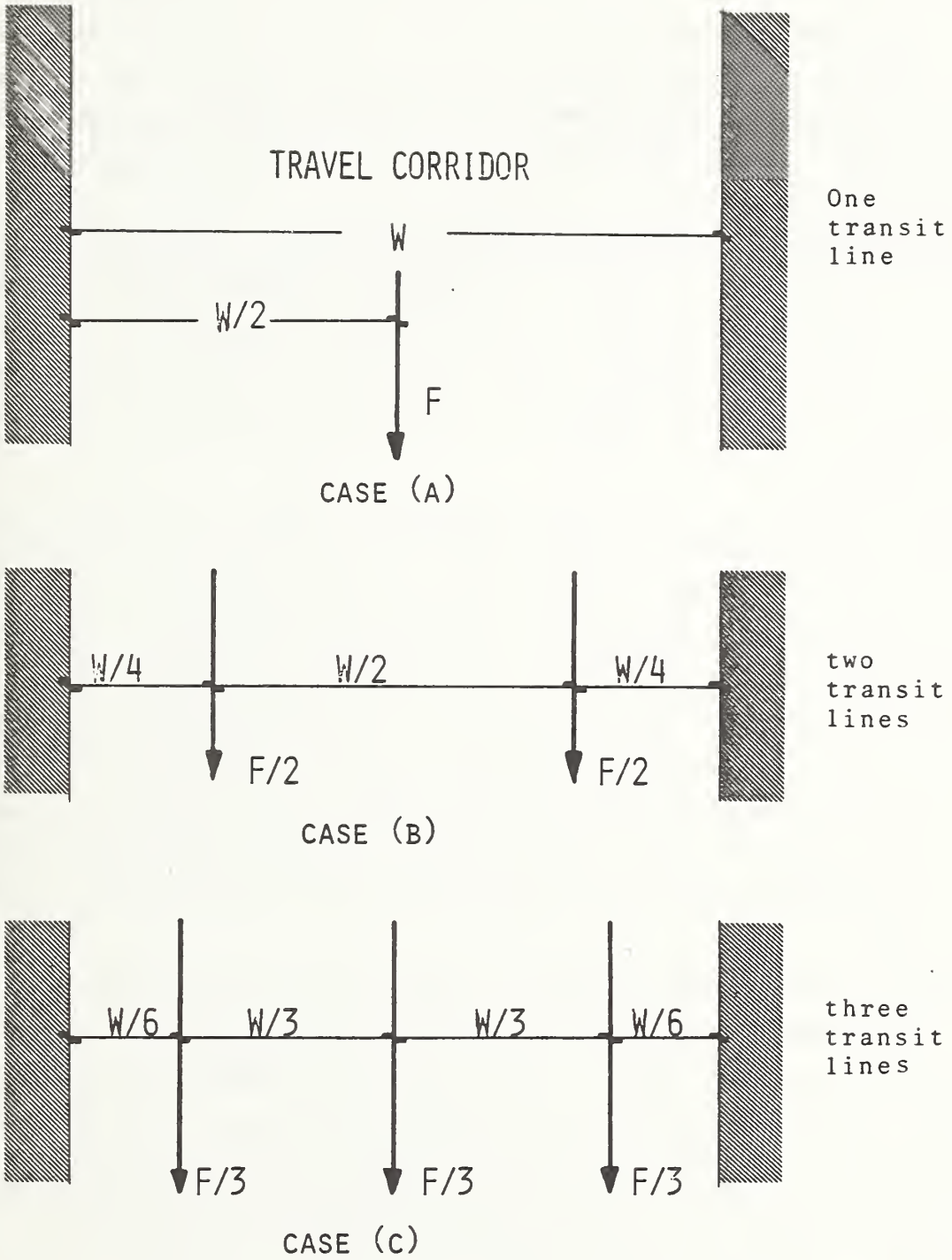


Figure 2.9. Relationship between line spacing and frequency of service for a given fleet size

Round-trip speed V_c is the average speed of a transit vehicle for a round trip, including terminal times. If the cycle time T [min], round-trip speed is

$$V_c[\text{km/h}] = \frac{120L}{T}. \qquad (2.2)$$

This speed is particularly important for the transit operator, since it directly affects the number of vehicles required for a given service and thus its operating cost and labor productivity.

Infrastructure of a transit network consists of all fixed facilities used for providing the service. These include vehicles, terminals and stops, maintenance facilities, private rights-of-way, and other capital investments. The infrastructure is largely determined by demand characteristics, level and quality of service which the operator attempts to provide, and the financial commitment of the local community.

Areas which have very low transit demand should have a correspondingly low investment in infrastructure. In such areas the service is usually provided by a fleet of buses or minibuses. The ability to achieve high load factors and a desired service frequency depends in a large part upon the size of the vehicles used. For maintenance purposes it is usually advisable for smaller transit agencies to utilize a single type or size of vehicle, so that the choice of the optimal vehicle size for each type of service may be limited. However, larger transit systems which have a wide variety of routes serving different levels of demand usually can have several types of vehicles and different modes; they often use minibuses, buses and different rail modes for services into and within low density suburban areas.

In general, the implementation of a Timed Transfer System (TTS) does not require a great deal of additional investment in infrastructure. For reasons to be explained in a later section, there may be some additional vehicle requirements to meet the uniform headway and frequency requirements of a TTS operation. The installation of an off-street transfer terminal, while preferable, is not always essential, as there are several acceptable designs for placing the timed transfer terminals on city streets.

An area committed to good transit service usually views investment in additional infrastructure as an evolutionary process which improves the quality of transit service and thus attracts new riders. The public and potential riders will look much more favorably upon a network which includes new vehicles, priority bus lanes, and well-designed passenger terminals than one with similar frequencies but without such facilities.

Operating costs are affected by network design in several ways. First, extensiveness of routes and their overlaps on trunk sections should be planned so that consistent load factors can be achieved throughout the network. Second, alignments should follow streets or rights-of-way which have as little congestion and interferences by other traffic as possible. Third, lengths of routes should be such that for average speeds scheduling is possible without excessive terminal times. Finally, network should provide adequate transfers for passengers among routes without delays to vehicles.

Section 3

TRANSFERS

3.1 The Role of Transfers in Transit Services

Passenger transfers between transit routes or modes represent an important component of transit travel. No transit network can serve all trips by direct routes without any transferring. Actually, the more transferring is performed, the easier it is to operate different routes efficiently, each one specifically designed to its physical conditions, volume and character of demand.

Transfers do, however, cause a certain delay in a passenger's travel; they also require some walking, orientation and other actions which may involve time and effort.

The planning, facility design and scheduling of transfers is of great importance for both transit system efficiency and user convenience and attraction. If a transit system provides easy, simple, fast and convenient transfers, its entire network can be operated very efficiently and it can attract most potential users. If, on the other hand, transfer locations are poorly designed, unsafe and unpleasant, and schedules are not coordinated, transferring may be such a serious obstacle, that it deters many potential passengers from using transit services.

Since transit transfer facilities in many U.S. cities have been badly neglected in recent decades, there has been a widespread belief that transfers per se are always major deterrents to transit travel and that only transit services offering direct travel by a single vehicle can compete with the automobile. However, there have been many extremely successful operations of transit systems with large numbers of transfers in European countries and Canada, and recently in several U.S. cities. These systems have utilized modern design of facilities and numerous innovations in transit operations. Their success clearly shows that transfers need not be obstacles to transit use. Actually, efficient design and operations of transfer facilities in many cities have increased transit travel substantially.

The following analysis of transferring in low density areas will provide a review of transit services and operational characteristics with respect to two basic features:

a. Headway length (or, inversely, frequency) and

b. Type of route.

Service characteristics which will be examined include convenience of transferring (time involved), number of possible transfers, their directions, and importance of transferring for the functioning of different transit networks. In cases where the nature of routes or headways lead to poor transferring conditions, the role of a timed transfer system (TTS) will be defined along with the potential improvements which its implementation can bring over conventional operations.

3.2 Impact of Headway Lengths of Transfers

Headway, defined as the time between passing of two successive transit vehicles on a route, is determined for each route as a function of its passenger volume, capacity of transit units (vehicles or trains), and the desired level of service (load factor and policy headway, i.e. the headway operated when capacity requirement does not govern). Headway length is one of the important factors upon which passengers make their modal decisions, since it directly affects waiting and transferring times, and thus overall travel time.

Transfers among transit routes vary considerably with their headway lengths. If, for a general analysis, routes are classified into those with short headways (generally, $\leq$ 10 min) and those with long headways (>10 or >15 min), transfers among them have the following characteristics.

Case 1: short-to-short headway. Transferring from a route with short headway to another route with short headway, typical for heavily traveled urban routes, involves very short transfer time. Passenger convenience is very good and there is no need for any special schedule coordination at transfer points.

Case 2: long-to-short headway. Transferring from a route with long headways to a route with short headways, typical for feeders arriving to a trunk line, also involves short transferring times even without any schedule coordination. As in case 1, there is no need for any schedule adjustments at transfer points.

Case 3: short-to-long headway. Reverse transfers to those in case 2, i.e. the ones occurring from a trunk to feeder routes with much longer headways, may involve long transfer times. Actually, the waiting times vary from very short ones to those equal to the long headway on the feeder route to which passenger is transferring. Thus the degree of inconvenience varies randomly. This uncertainty can be eliminated when schedules for all routes

are provided for passengers, so that each passenger can plan his/her trip and take the vehicle on the trunk line which connects with his particular feeder with minimum delay.

Case 4: long-to-long headway. Transfers between two routes with long headways can be classified into the following three "subcases" by the relationship of headways on the two routes.

Case 4a: long-to-long, equal headways, synchronized, with overlap standing times. When the connecting routes have vehicles arriving at the same times and standing there for a few minutes to allow exchange of passengers, very easy and convenient transfers are provided for in both directions.

Case 4b: long-to-long, equal headways, but no overlap standing times. Vehicle arrivals on two connecting routes are always in the same time sequence. It is possible to make convenient transfers from one route to the other (A to B), but not in the opposite direction (B to A), since no overlapping standing time is provided.

Case 4c: long-to-long, different headways. No coordination is possible. Transfer times are random, can be very long.

In low density areas most routes have long headways, and a few have short ones. All cases except case 1 can usually be found.

Table 3.1 presents a summary review of characteristics of individual types of transfers classified by headways of originating and destination routes. As is intuitively clear, transferring from any route to one with short headways is always convenient (cases 1 and 2); transferring to a route with long headways from any other route varies from very convenient with TTS (case 4a) to very inconvenient with different headways (case 4c).

Coordination of schedules is not necessary in the cases 1 and 2 (transferring to routes with short headways), but it is very important in the cases 3, 4a and 4b. In the case 4c schedules cannot be synchronized, except for some particular runs.

Table 3.1 Transfer times between routes with short and long headways

Originating route \ Destination route	Short headway	Long headway
Short headway	Case 1 Always short, convenient	Case 3 Varies greatly. Information about connecting runs required.
Long headway	Case 2 Always short, convenient	Case 4 Variable depending on headways: (a) Equal and simultaneous - all transfers convenient (TTS); (b) Equal but not simultaneous - transfers in one direction convenient if coordinated; (c) Different - impossible to coordinate; long transfer times.

3.3 Characteristics of Transfers by Type of Route

The character of transfers is influenced considerably by two aspects of the routes among which transfers take place.

The first aspect is the relationship of each route to the transfer point: whether the route terminates at the transfer point, or passes through it (i.e. the transfer point is one of the stations along the route). With respect to this aspect, routes will be referred to as terminating (t_e) and through (t_t) routes.

The second aspect is whether all routes are of similar nature (frequency, capacity, physical characteristics - mode), or one of them is a dominant or trunk route (line) with considerably higher frequency, capacity and performance in general then any other route, while the others, with low frequency and capacity, represent its feeders with a collection/distribution function. In addition to the impacts of different frequencies (headways) discussed in the preceding section, this aspect of route type influences transferring patterns

of passengers (many-to-many among equal, and many-to-one, one-to-many between trunk and feeders).

Suburban bus routes meeting at different points often have similar nature, while the trunk/feeder situation is typically found where suburban bus routes converge on a major radial route leading toward the central city. The trunk route may be rail or bus, but with much higher frequency and capacity than its individual feeders.

Table 3.2 presents descriptions and characteristics of transfers classified by the above defined aspects of transit route types. Three combinations of terminating and through routes, expressed in general terms ("N" routes), are given as cases 1-3; the other three cases are with specific numbers of routes, representing the simplest cases.

All the cases are described for two types of situations: for similar routes, and for trunk - feeder relationship. Each case will be discussed here.

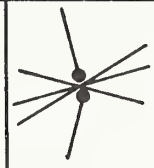
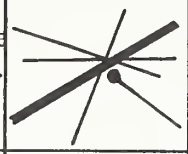
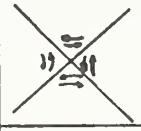
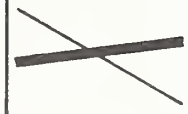
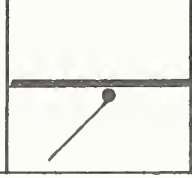
Case 1 is the simplest: when all of N_e routes coming to a transfer station terminate, the total number of transfer permutations k is:

$$k = N_e (N_e - 1). \qquad (3.1)$$

This type of station is the prime case for application of TTS to minimize passenger delays and integrate transit network. A typical example of this case is found where many suburban lines have a common terminal; they may be of similar nature (columns 5-7 in Table 3.2), or there can be the case of suburban low-frequency routes terminating at a trunk line terminal (columns 8-10). This case is found, for example, at most rapid transit terminals in Philadelphia, Washington and Atlanta.

In the latter case, trunk/feeders, application of TTS again greatly facilitates transfers among the feeders, but it would create uneven loadings on the trunk line: due to its much shorter headways many of its transit units would meet no feeders, while a few would get passenger loads from all feeders. Therefore TTS should be used only if transferring among feeders is substantial and, whenever possible, feeders should be divided into 2-3 groups which would meet simultaneously. If this transferring is negligible, feeders should be staggered as much as possible to provide even loading on the trunk. Naturally, if there are only 3 to 4 lightly traveled bus feeders to a high capacity rapid transit line, the problem of uneven loading is negligible.

Table 3.2 Classification of transfers by types of routes

Case number (1)	Number of lines: Terminating (2)	Number of lines: Through (3)	Transfer permutations (4)	Similar lines/routes: Sketch (5)	Similar lines/routes: Typical case (6)	Similar lines/routes: Comment (7)	Trunk with feeders: Sketch (8)	Trunk with feeders: Typical case (9)	Trunk with feeders: Comment (10)
1	N_e	0	$N_e(N_e - 1)$		Many suburban lines terminating	Coordination between lines needed. TTS can be applied successfully.		Trunk line terminating with many feeders	Requires coordination in case of transfers among feeders (TTS)
2	0	N_t	$4N_t(N_t - 1)$		Any point with several intersecting transit lanes	TTS desirable, but causes delay of through passengers		Trunk line station where feeders intersect	TTS possible. Feeders' arriv and departures "around" trunk stopping.
3	N_e	N_t	$(N_e + 2N_t)^2 - (N_e + 4N_t)$		Many transit lines terminate or pass through	TTS desirable; easier to achieve than with case 2.		Trunk line passes through where feeders intersect and/or terminate	
4	2	0	2		Terminal point of two suburban lines			Trunk line terminal with one feeder	
5	0	2	8		Intersecting point of any two transit lines			Trunk line station where a feeder intersects	
6	1	1	4		Point where one line terminates, another passes through			Trunk line passes through and feeder terminates	

Case 4 represents the simplest situation of this type: two routes with common terminus. The number of possible transfers is two: one from route A to B, and one from route B to A.

Case 2 represents transfer stations at which all N_t routes pass through. The total number of transfer permutation k is:

$$k = 4N_t(N_t-1). \tag{3.2}$$

This is a very large number. For only two intersecting routes (shown in Case 5) there are already 8 possible transfers. It is therefore highly desirable to organize a TTS for routes, among which there is appreciable number of transferring passengers, and which have similar headways. However, since this transfer point is in the middle of both routes, it causes delay to all non-transferring passengers. To minimize that delay and prevent eventual loss of through passengers on the lines, it is very important to insure short layover times through precise scheduling, reliable operation and convenient design of transfer points (short transferring distances).

Transfers between a trunk line and its feeder routes intersecting it when trunk headways are long (e.g. on regional rail line) must be organized differently. Since it is usually impossible or undesirable to delay vehicles on the trunk line, feeder routes should be scheduled so that their vehicles arrive prior to trunk line vehicles, and depart after the trunk line vehicles depart. Thus the trunk line is not affected, while feeders are delayed more than at transfers among similar routes. This type of TTS operation is justified whenever the feeder function dominates operations of lightly traveled routes.

Case 3 represents the most general situation: N_e terminating routes meet N_t through routes at a joint terminal. The number of possible transfers k among these routes, given by the expression

$$k = (N_e+2N_t)^2 - (N_e+4N_t), \tag{3.3}$$

is given in Table 3.3.

Equation (3.3) is the most general one, incorporating terminating and through routes. When all routes are terminating, case 3 "collapses" into case 1; and since $N_t = 0$, Eq. (3.3) simplifies into Eq. (3.1). If all routes are through routes, one obtains case 2, and since $N_e = 0$, Eq. (3.3) becomes Eq. (3.2). Therefore Table 3.3 can be used to find the number of transferring permutations among any number of terminating and through routes. For example, at a transit station where 2 through routes intersect and 3 routes terminate, there are 38 ways in which passengers can transfer among those routes.

Table 3.3 Number of transfer permutations among N_e terminating and N_t through routes

N_t \ N_e	0	1	2	3	4	5	6	7
0	0	0	2	6	12	20	30	42
1	0	4	10	18	28	40	54	70
2	8	16	26	38	52	68	86	106
3	24	36	50	66	84	104	126	150
4	48	64	82	102	124	148	174	202
5	80	100	122	146	172	200	230	262
6	120	144	170	198	228	260	294	330
7	168	196	226	258	292	328	366	406

Case 6 in Table 3.2 shows the simplest situation of a transfer between a terminating and a through route: where only two such routes meet. There are only 4 possible transfers and coordination is best achieved if vehicles on the terminating route arrive before and leave after vehicles on the through route pass through. This condition is similar to the one where feeders intersect a trunk line (cases 2 and 5, columns 8-10), except that no additional delay is caused on either route by this scheduling: terminal time on the terminating route is used for "overlap" with the arrival on the through route.

The preceding analysis of transfers among transit routes clearly shows a great variety of conditions at their contact points. To achieve convenient transfers and thus offer an integrated network service, transit operators must carefully analyze types of routes, their relationships (relative significance), directions of transferring (which often varies among different periods of day), headways, layover times, etc. While in some cases TTS is not necessary (e.g. between routes with short headways); in others it can be beneficial, but it involves certain inconvenience (e.g. between intersecting routes); finally, in some cases the only way to achieve any coordination is through TTS (e.g. among terminating routes with long headways).

Section 4

TIMED TRANSFER SYSTEM

4.1 Basic Route and Operating Elements

A TTS must be designed with close coordination between its network elements and operating characteristics (e.g. distances between focal points, and travel speeds among them) and operating elements such as headways, fleet size and others. To present TTS scheduling, these elements must be defined.

Route (line) length - L (km or mi) - distance between two terminals of a transit route (line) path.

Operating time - T_o(min) - time during which a transit vehicle traverses the route between terminal points.

Terminal time - t_t(min) - time during which a vehicle is standing at the terminal point of a route.

Cycle time - T(min) - round trip time on a line, or time interval between two successive departures of a transit vehicle from the same terminal point. Assuming equal operating time in each direction and equal terminal times (which is not always the case), the cycle time is:

$$T = 2(T_o + t_t). \tag{4.1}$$

Headway - h(min) - time interval between passings of two successive vehicles at a given point on the route.

Policy headway - the minimum headway operated determined by the desired level-of-service rather than by the capacity requirement.

Pulse headway - h_p(min) - the basic headway in a TTS, i.e. the time between successive "pulses" when vehicles on all (or most) routes simultaneously depart from a focal point or terminal.

Frequency - f($hour^{-1}$) - number of vehicle (or transit unit) departures on a route during one hour. It is the inverse of headway.

Round-trip or commercial speed - V_c(km/h or mi/h) - the average speed of a vehicle during a round trip. It is computed as:

$$V_c = \frac{120L}{T} \quad , \tag{4.2}$$

where T is expressed in minutes.

Operating speed - V_o (km/h or mi/h) - the average speed of vehicle travel between terminals, not including terminal time. It is computed as:

$$V_o = \frac{60L}{T_o} . \tag{4.3}$$

Number of vehicles on a route or fleet size - N - is directly related to cycle time and headway:

$$N = \frac{T}{h} . \tag{4.4}$$

4.2 Relationships among Operating Elements in a Unifocal Network

The simplest TTS network has one focal point (terminal) for simultaneous transferring among all converging routes (Fig. 4.1). This network type may incorporate radial routes which start from the focal point and "radiate" in individual directions, and diametrical or through routes which pass through the focal point and have two radial sections. Choice between these two types of routes depends on passenger volumes, their origin-destination (O-D) patterns, policy headways and reliability of transit operations. Radial routes are preferred when most trips terminate at the focal point, passenger volumes or operating policies require different headways on different routes (multiples of each other), or when reliability is poor. When a reasonable number of trips on two routes with the same headway goes through for focal point and service is reliable, through (diametrical) routing is preferable.

Once the basic alignments and types of routes are chosen, the relationship among the operating elements described in the previous section can be analyzed.

The relationship between pulse headway and other operating elements is:

$$h_p = \frac{T}{N} . \tag{4.5}$$

Therefore, the cycle time is a product of the fleet size and headway:

$$T = N \cdot h_p . \tag{4.6}$$

Other elements which determine operation of a TTS are route length and round-trip speed. The relationship among them is:

$$L = \frac{T \cdot V_c}{120} . \tag{4.7}$$

Substituting the expression for T from Eq. (4.6) into Eq. (4.7) yields:

$$L = \frac{N \cdot h_p \cdot V_c}{120} . \tag{4.8}$$

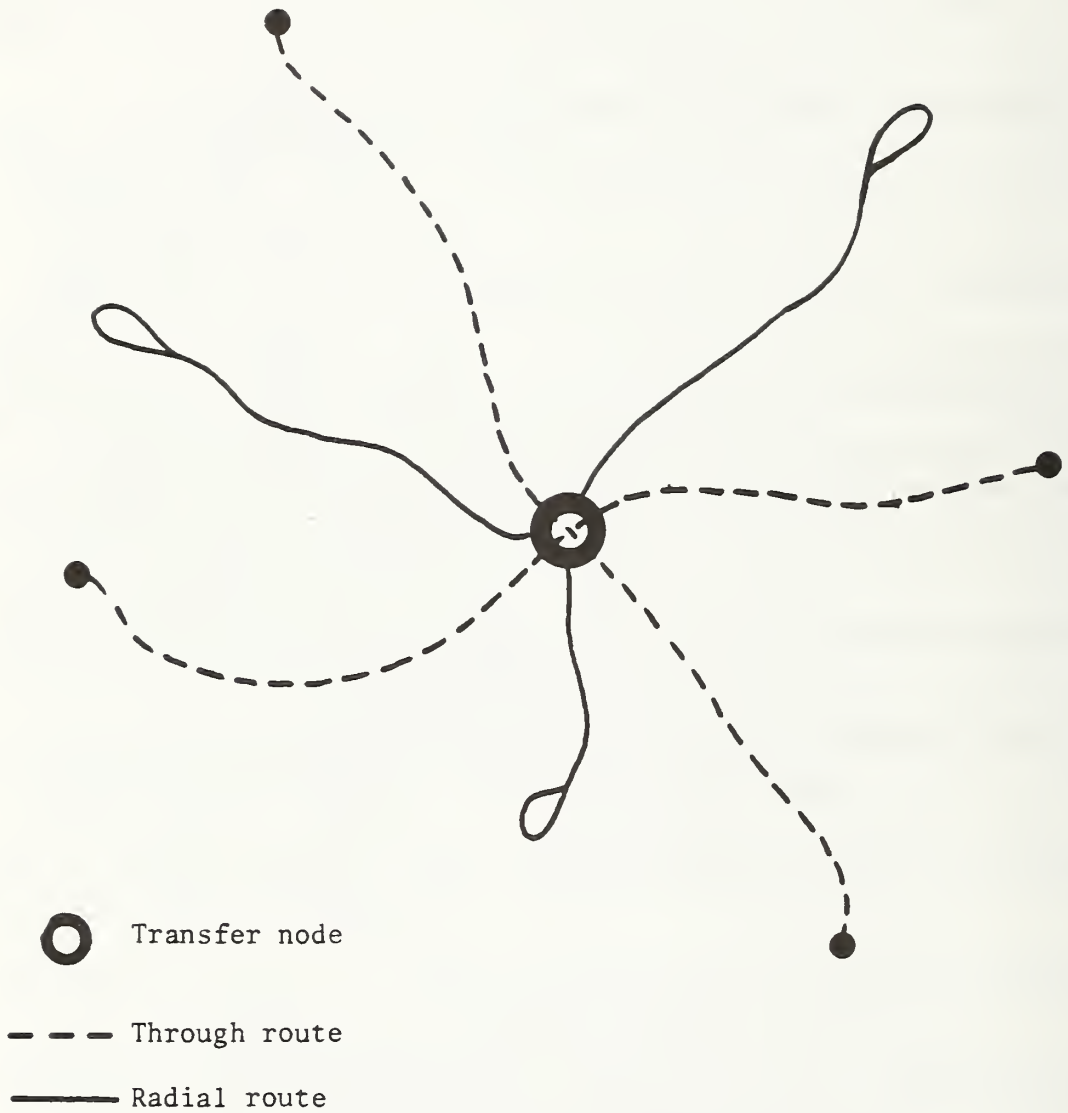


Figure 4.1 Unifocal TTS network

Since in a TTS

$$f = \frac{60}{h_p} \quad , \tag{4.9}$$

Eq. (4.8) can be rewritten to give the relationship for any route i as:

$$L_i = \frac{N_i \cdot V_{ci}}{2f_i} \quad . \tag{4.10}$$

This expression gives the length of each radial route or each half of a diametrical route for their respective operating characteristics.

When radial routes operate with one vehicle only (which is common in low density areas), Eq. (4.10) simplifies into:

$$L_i = \frac{V_{ci}}{2f_i} \quad . \tag{4.11}$$

If roundtrip speed V_c is equal on both legs of a diametrical route, the lengths of each leg must be equal. The relationship between route length L and frequency f for two different round-trip speeds is shown in Fig. 4.2. Different fleet sizes N_i make the plotted families of curves. In general, the route length must decrease as frequencies increase unless additional vehicles are added to the route.

Expressions for number of vehicles on a route N and frequency f can be derived in a similar manner from Eq. (4.10):

$$N = \frac{2L \cdot f}{V_c} \tag{4.12}$$

and

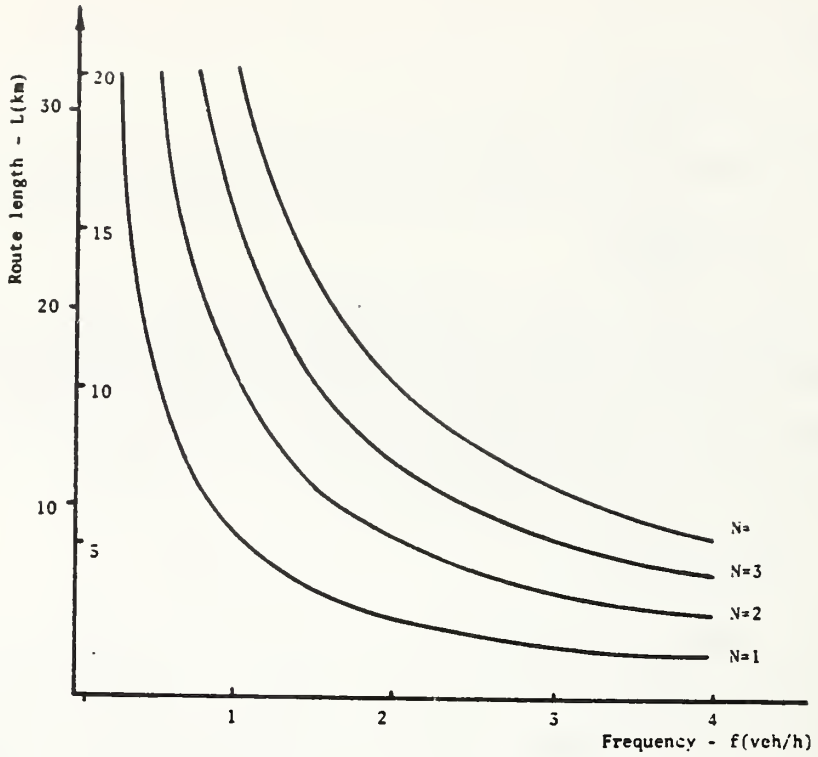
$$f = \frac{N \cdot V_c}{2L} \quad . \tag{4.13}$$

Diagrams in Fig. 4.3 show number of vehicles as a function of route length for a set of frequencies. For any given route length the number of vehicles on a route increases proportionally to increases in frequency.

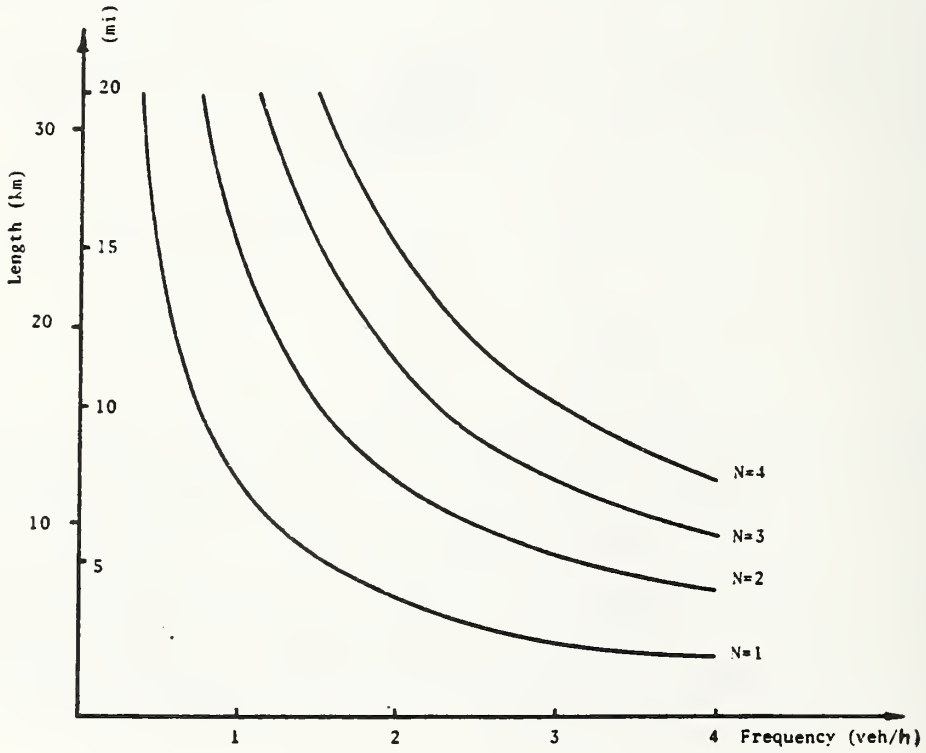
Figure 4.4 shows frequency of service as a function of number of vehicles on the route for given round-trip speed and a set of route lengths. The relationship shows how frequencies can be increased as additional vehicles are placed in service on the route.

4.3 TTS Scheduling

In an uncoordinated system, the basic operating elements [L, T, h(f), V_c and N] for each route are usually independent from those on any other route in the network. However, in a TTS network the headway (and therefore frequency) must be the same on all routes, or an exact multiple of headways on other

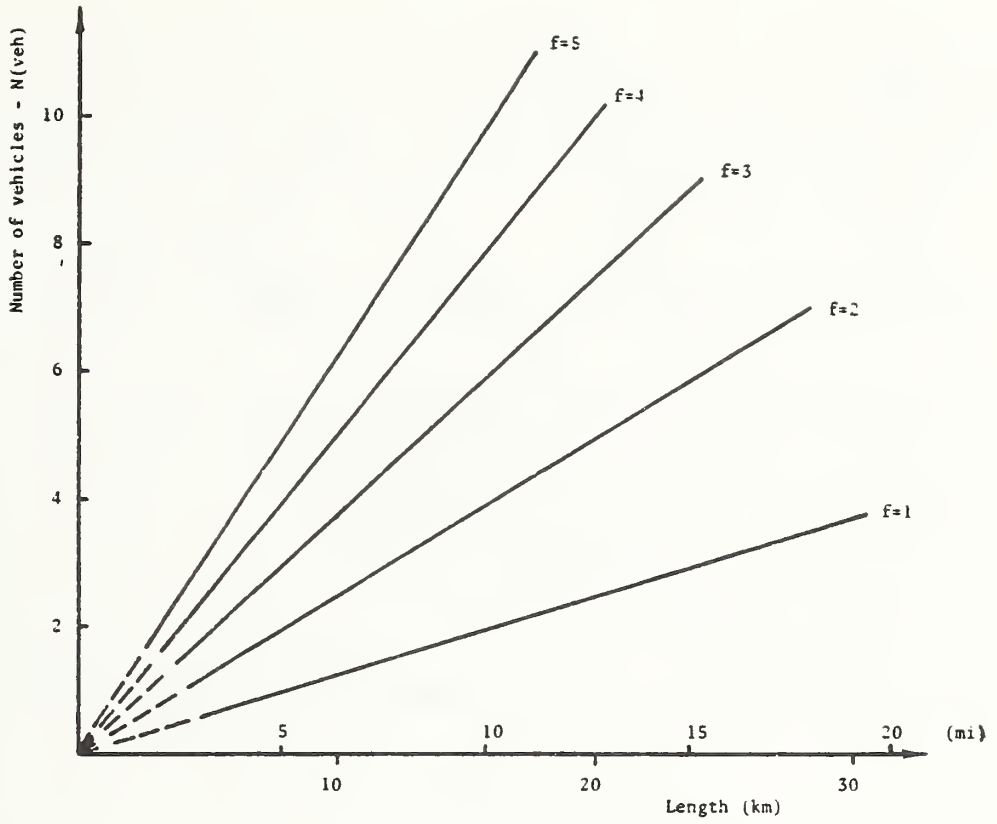


(a) V_c = 16 km/h

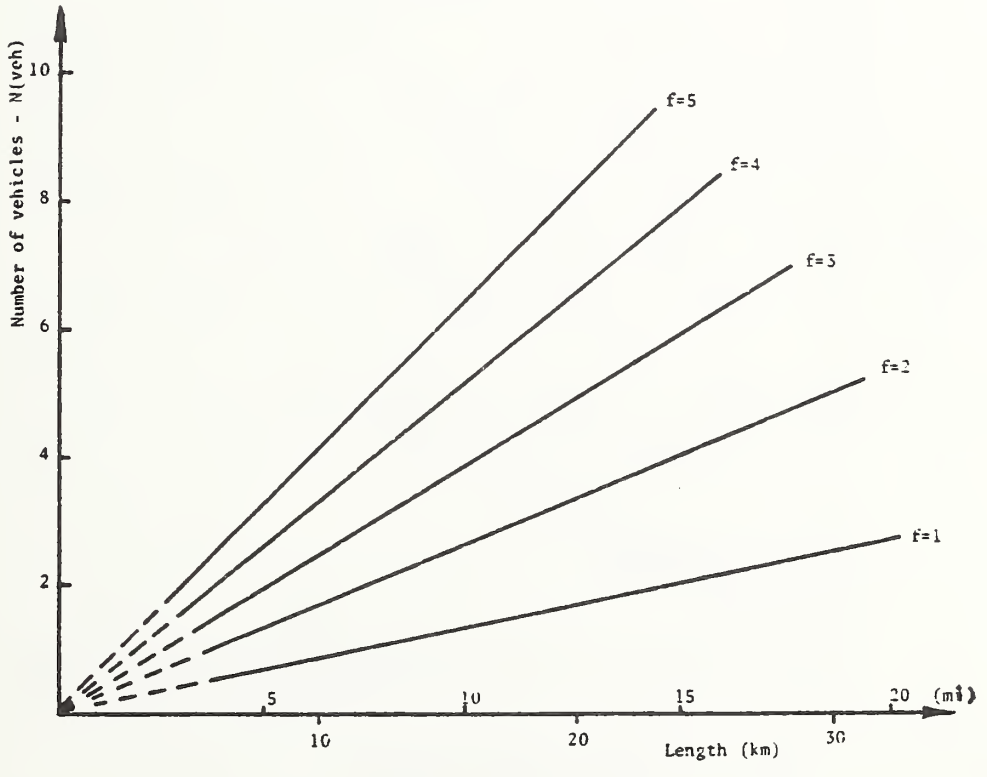


(b) V_c = 24 km/h

Figure 4.2 Route length as a function of frequency, fleet size and round-trip speed: $L = N \cdot V_c/(2f)$

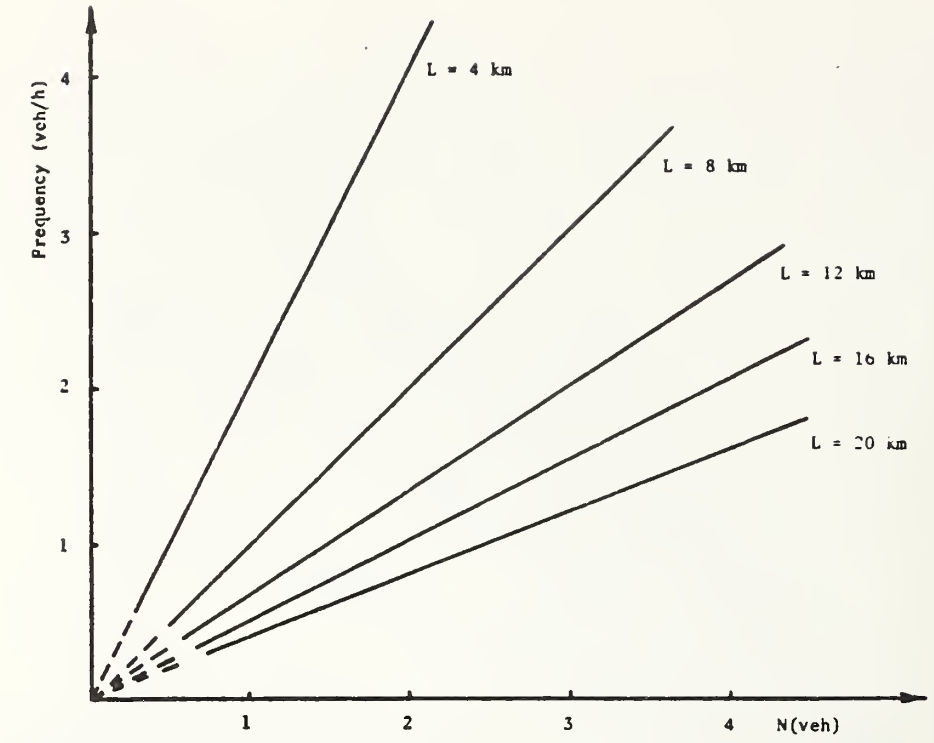


(a) V_c = 16 km/h

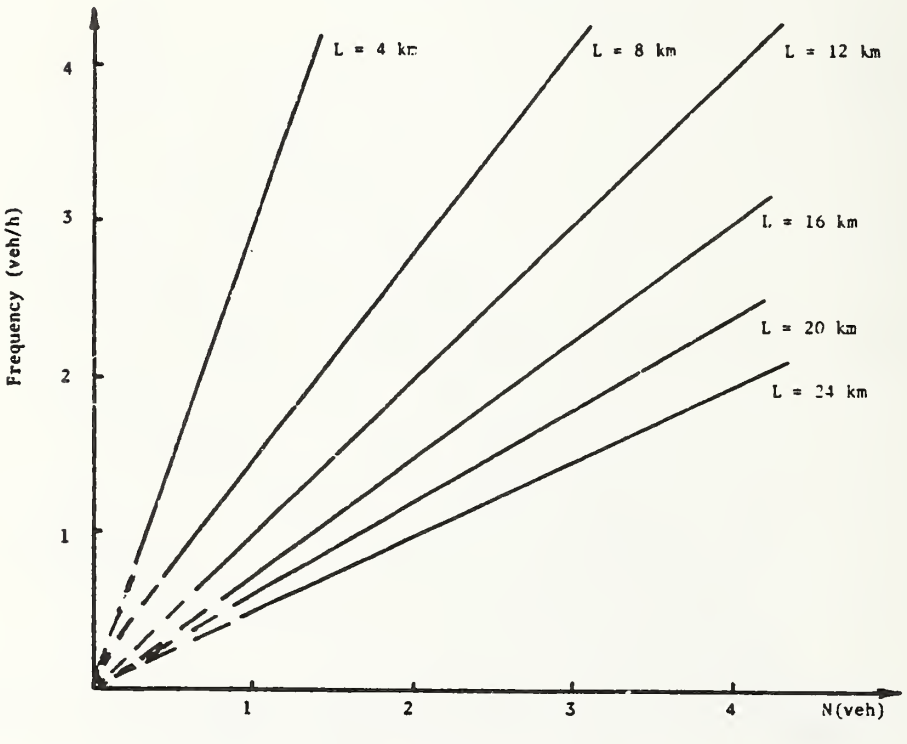


(b) V_c = 24 km/h

Figure 4.3 Fleet size as a function of route length, frequency and round-trip speed: $N = 2L \cdot f/V_c$



(a) V_c = 16 km/h



(b) V_c = 24 km/h

Figure 4.4 Frequency as a function of fleet size, route length and round-trip speed: $f = N \cdot V_c / 2L$

routes. For example, all routes coming to a focal point must have headways of 15 min., or, exceptionally, 30 or 60 min. Therefore each route, or section of a route from a focal point outward must satisfy the following equation:

$$h_i = j \cdot h_p = j \frac{120L}{N \cdot V_c}, \qquad (4.14)$$

where j is an integer : for equal headways j=1, for multiples it may be j=2,3,4, etc.

This equation defines the relationship of operating elements of all the routes in a TTS network. In many cases independent routes which have different headways (as determined by passenger demand or by policy considerations) must be reorganized to have the uniform headway for a TTS network.

The selection of a pulse headway h_p for all routes arriving at the focal point is the most important operational decision. Since the headways should always be divisible into one hour to enable easy memorization of schedules by passengers, pulse headways should desirably have one of the following values: 10, 12, 15, 20, 30 or 60 minutes.

The value of h_p depends on several factors, and it may vary from a few minutes to one or two hours. Very short headways can be used only on transit systems with highly reliable service, i.e. those with fully controlled rights-of-way (category A). For example, rapid transit systems in New York, Hamburg, and Moscow have simultaneous arrivals of trains from different lines and exchange of passengers every 5, or even every 2.5 minutes. On the other hand, bus routes operating along congested streets may require layover times of 6 to 8 minutes, so that they can use practically only headways of 15 minutes or longer.

Two major factors which influence the choice of h_p are passenger demand and policy headway (the latter is also influenced, although not exactly determined, by the former).

Consequently, in planning a TTS one must consider the demand, required level of service (policy headway), and expected reliability of service on each route. However, since in most cases TTS must have only one common headway (or its exact fractions or multiples), and that headway is rather long ($\geq$15 minutes) and should be divisible in 60 for ease of scheduling, the choice tends to be limited to only 15 (and its multiples, 30 and 60), or 20 (40,60) min. to satisfy all these requirements.

The selected pulse headway h_p should be as close as possible to the headways which are optimal for the majority of routes based on their individual operating conditions. It is usually better to select h_p somewhat longer rather than shorter than the existing headways since it is always easy to obtain a common headway by extending cycle times, while their shortening may require a greater number of vehicles and therefore increased costs of operation.

Several methods can be used to convert different headways into the uniform pulse headway. As an example, suppose that six routes planned for an unifocal network have headways of 16, 18, 20, 24, 30, and 40 minutes. Planning a TTS for an area already served by several independent routes should consist of three steps described here.

4.3.1 Data Collection and Analysis of Existing Routes. Several types of data should be collected for each route:

a. Passenger demand, including boarding/alighting profile and maximum load section for different periods of day. If available, O-D information is also very useful for planning of transfers.

b. Operational elements, such as the present route lengths, headways, cycle times, operating and round-trip speeds and fleet sizes - again for each scheduling period in the day.

c. Detailed information of route characteristics. Each route can be divided into fixed and optional sections. Fixed sections are those that must be served: major streets and avenues, usually along the main corridor between the terminals. Optional sections are deviations from the main direction into individual neighborhoods, shopping areas, plants, etc. which may be modified, shortened or eliminated from the route if necessary. In some cases it may be possible and desirable to extend these optional sections, particularly those at outer ends of routes.

Although it is sometimes an arbitrary decision to classify a section into one of these categories, it is very useful to have this information so that in scheduling it is clear which sections must be served and which may be subject to modifications.

4.3.2 Determination of the Pulse Headway. After the above information for each route is analyzed, feasible alternative headways should be selected. In most cases, headways of 15, 20 and 30 minutes should be considered for policy headway. In general, the shorter the headway, the higher

the level of service, but also the operating costs. Considering this trade-off, evaluation of these headways might be, for example, as follows:

15 minutes would provide an excess of service on several routes. It should be considered only if it is expected that TTS will generate a substantial ridership increase, or a higher level of service is intentionally offered.

20 minutes probably provides the best compromise among all the routes. The route with 15-min. headway should be carefully studied to find out whether or not the increase of headway is acceptable.

30 minutes appears to be too long a headway for four of the six routes, so that it should be rejected.

After the pulse headway h_p is chosen, each route must be made to conform with it in order to meet the requirements of a TTS. For the routes with headways very different from h_p the adjustment may either represent a significant deterioration of service (lengthening of headways), or a greatly increased operating costs (shortening of headways). To avoid these problems, the following solutions are possible.

a. Routes with headways significantly less than the pulse headway can have their headways adjusted to exact fractions of the pulse headway: $h_p/2$; $h_p/3$; etc.. This can assure adequate service on heavily traveled routes. However, since only every other or every third vehicle connects with the vehicles from other routes, an effective passenger information system must be organized to inform riders about which runs provide direct transfers. In our example, if a 30-minute pulse headway was chosen, the most heavily traveled route can have a headway of $15(h_p/2)$ or $10(h_p/3)$ minutes.

b. Routes with headways significantly greater than the pulse headway can have their headways adjusted to exact multiples of the pulse headway: $2h_p$; $3h_p$; etc.. Again, an effective passenger information system is required since passengers transferring from heavily travelled routes to these lightly traveled routes need to know which runs provide direct transfers. In our example, if 20 minutes was chosen as the pulse headway, the most lightly travelled route (h=40) would probably retain its 40-minute headway.

4.3.3 Scheduling of Routes for the Selected Headways. Once the headway for each route has been selected, operation of each route must be carefully planned to ensure that the best level-of-service/operating cost combination is achieved. The change of headways and cycle times from the present to the selected ones is done through an examination and adjustments of one or more of the physical and operating elements of each route.

From Eq. (4.7) cycle time is a function of route length and round-trip speed:

$$T = \frac{120L}{V_c} , \qquad (4.15)$$

while Eq. (4.5) shows that pulse headway depends on cycle time and fleet size. Therefore, to achieve a schedule which fits the required h_p, adjustments of the following elements should be considered.

a. Changes of round-trip speed - V_c. A higher round-trip speed will permit shorter headways while using the same number of vehicles, while lower V_c produces the opposite effect. Increase of V_c is more desirable not only for level-of-service reasons, but also for reducing operating costs.

There are a number of measure which can be undertaken to increase transit speeds*. Increase of round-trip speeds can be effected by three types of measures.

First, reductions of terminal times t_t. These times usually amount to some 10-15% of cycle time. Their reduction is possible when operations of the route are reliable, so that reserve time for delay recovery is not needed. If necessary, layover times at transfer points may be shorter for some routes than for the others if the schedule requires that. Labor practices and/or union contracts which stipulate the minimum length of terminal times may constrain the reduction of cycle times in some cases. The second method of changing V_c is by implementation of transit priority procedures. Examples are exclusive transit rights-of-way, lanes, or street signals which can be actuated by transit vehicles. Although these measures can be introduced only by local traffic authorities and are often not considered for low density areas, there are cases where they can be justified. This often occurs on road where transit lines consist of more than one route, so that frequency is high; typically this is found on approaches to transit terminals where traffic congestion can be severe, and improvements through priorities very significant.

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*For a detailed description of such measures see Ref. [9], sections 5.6-5.8.

The third method in which the transit operator can bring about changes in V_c is through improved passenger handling and fare collection procedures. For example, decreasing the number of transit stops (where stops are close together), more efficient fare collection procedures, such as self-service, boarding or alighting through more than one door during peak hours, etc. These changes are under full control of the transit agency.

b. Changes in route length - L. When substantial changes in cycle times T must be made, changes in route length may be appropriate. A reduction of T may be possible only if a section of a route is abandoned; its lengthening often creates the situation where a route may be extended at a negligible cost (instead of having an excessive terminal time, transit vehicle may serve an additional area).

For route changes some general principles should be borne in mind. Route extremities - sections toward outer terminals - benefit the riders from those areas; they do not directly affect any other riders. Diversions of routes on their central sections (mid-route) benefit the riders from the areas into which the route is diverted, but inconvenience all the riders traveling through that section. Mid-route diversions should therefore always be avoided, unless very few passengers ride the route through the diverted section.

In considering route length changes transit planners must analyze all route sections classified as optional (see Sec. 4.3.1). If shortening is required, one or more of the optional sections should be eliminated, primarily those attracting few passengers and those on the route section with through riders. If lengthening is desirable, extensions into new areas, particularly beyond the outer terminal (which is not a transfer point) should be primarily considered.

c. Changes in fleet size - N. In many cases changes of V_c and L cannot be made, or they are not sufficient to allow the change to a new h_p. Number of vehicles on a route must be changed. In most cases, the number increases - a vehicle must be added to reduce the headway. In rare cases, headway may be slightly lengthened and V_c increased, allowing reduction of N.

If "forcing" a common headway on all routes results in highly variable load factors among routes, transit agency may consider the use of two or three different types of vehicles, such as minibuses, 35-, 40-foot long buses, to achieve an optimal utilization of rolling stock.

The preceding discussion shows that implementation of TTS operations requires careful planning. Schedules for most routes must be modified to various degrees, but there are a number of methods in which the required modifications can be achieved. Each case should be analyzed individually to find the best solutions.

4.4 Elements of Multifocal Networks

The basic relationships among f, L, N, V_c and T which exist for a unifocal network also apply when one or more additional focal points are added to the network. However, the interaction between focal points introduces some additional scheduling considerations, particularly for routes which connect the focal points. An understanding of operations in a bifocal network, the simplest form of a multifocal network (Fig. 4.5), requires definition of the types of routes and pulsing nature of the system.

4.4.1 Types of Routes. TTS networks with more than one focal point can have three basic types of routes: radial, direct connector, and collector/distributor (C/D) connector. The first two exist in any multifocal system, while the latter is optional.

- Radial routes are those which go from one focal point "outward", i.e. they do not contact other focal points. One of their primary purposes is to bring passengers from outlying locations to the focal point. A radial route may continue through the focal point in another radial direction to form a diametrical route. Each of the two legs must have the same cycle (round-trip travel time), or an integer multiple of it.

- Direct connector routes serve at least two focal points. Their primary purpose is to transport passengers between focal points as quickly as possible.

- C/D connector routes also serve more than one focal point; however, their primary purpose is to serve the areas which lie between focal points. Thus these routes often make circuitous diversions off the road which provides the shortest path between focal points and have more stops than the direct connector route.

A diagram of these three types of routes appears in Fig. 4.5.

These route definitions are based on their relationships with the entire transit network. With respect to their type of operations, routes can be:

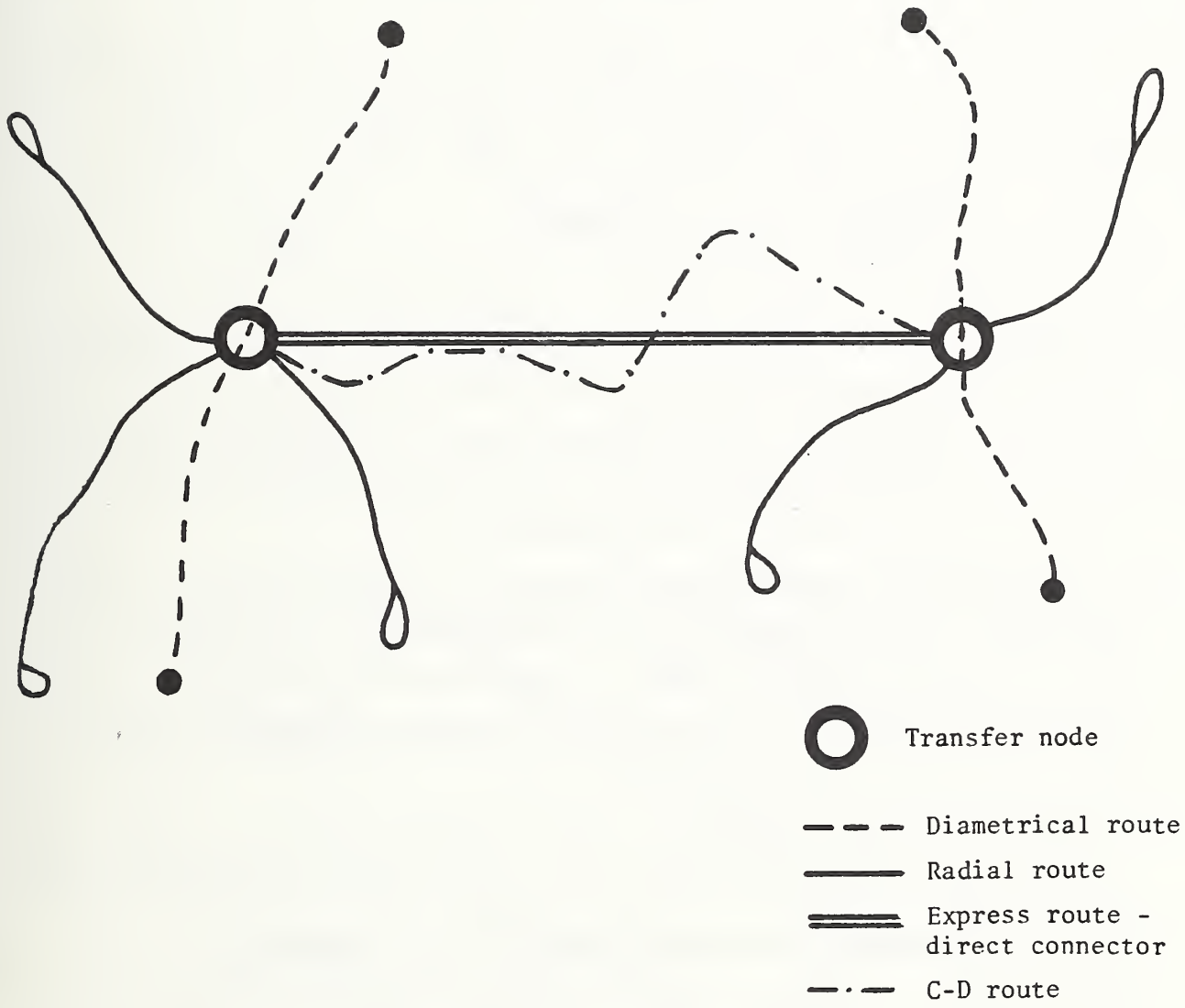


Figure 4.5 Bifocal TTS network

- Local, making stops along their path as frequent as service to the area requires.

- Accelerated, in which vehicles skip certain stops in a predetermined, fixed pattern. This includes skip-stop and express runs on some route sections.

- Express, where vehicles stop at only a limited number of locations along their route. Fast connection between few points is more important in this case than service to the area.

4.4.2 Staggered and Simultaneous Pulsing in a TTS Network. Pulsing refers to the uniform and simultaneous arrivals and departures of vehicles on different routes at a focal point or terminal. With any multifocal TTS there is an option between simultaneous or staggered pulsing of different focal points. A simultaneous pulse occurs when two or more focal points in the network pulse at the same time. The staggered pulse system occurs when the time of pulsing alternates between focal points.

The concepts of staggered and simultaneous pulsing are illustrated in Fig. 4.6 on an example of a bifocal network. The significance of these two types of operation for TTS network design is that they have different relationships between T, L, V_c and N, as Fig. 4.6 shows, so that in selecting focal points the transit planner has several options of sets of points and types of operation. The basic cases of applications of the two pulsing types and their operating characteristics are described next.

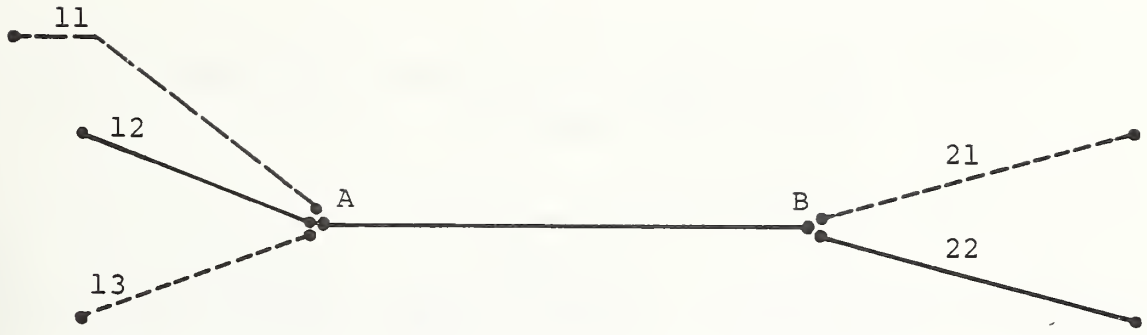
4.4.3 Relationships among Operating Elements in a Bifocal Network. The basic relationship affecting operations in a bifocal network is between cycle time on the direct connector route, T_d, and the basic cycle time of radial routes coming to the focal points, T_r. Situations which can be found in practice can be divided into three cases:

I. Equal cycle times: $T_d = T_r$;

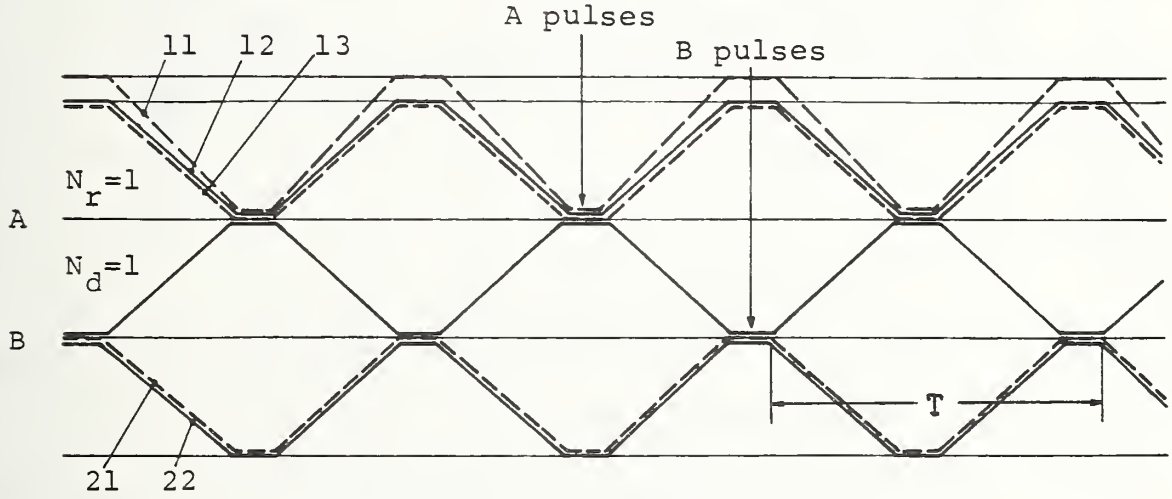
II. Cycle times on radials are twice longer than the direct connector's cycle time: $T_d = 0.5\ T_r$; and

III. Cycle times on radials are a half of the direct connector's cycle time: $T_d = 2\ T_r$.

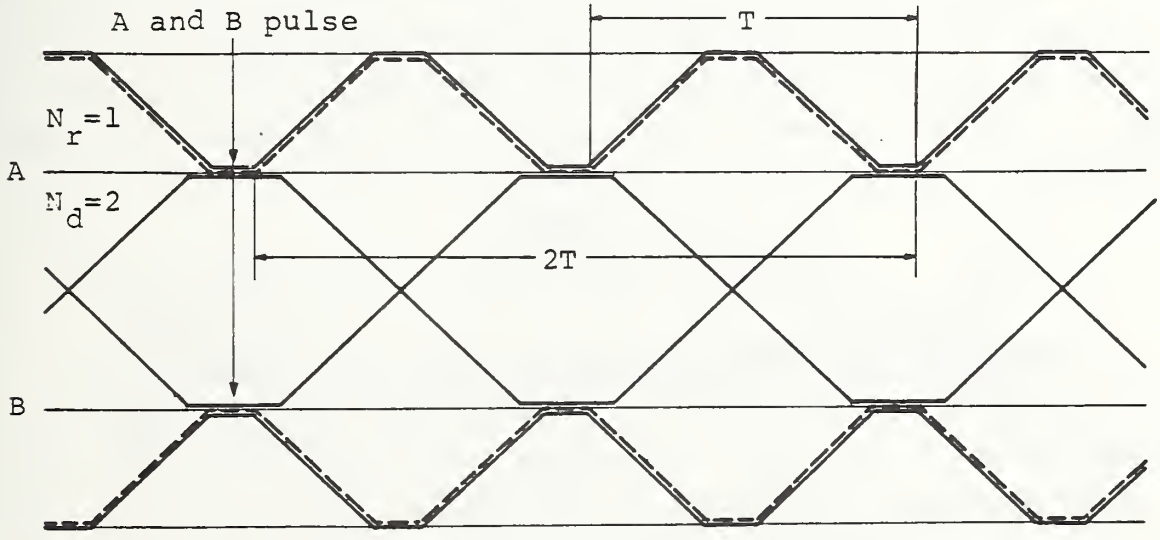
These three cases will be defined and compared for operation with the minimum possible fleet size N (the basic type of operation), with the requirement that during each pulse vehicles from all routes serving that focal point meet, i.e. that all routes have the same pulse headway h_p. Table 4.1 presents a summary of operating elements for all the cases which will be discussed here.



(a) Layout: connector and radials



(b) Staggered pulsing between A and B focal points



(c) Simultaneous pulsing at A and B focal points

Figure 4.6 The concepts of staggered and simultaneous pulsing in a bifocal network

Table 4.1 Relationships of route elements for different types of bifocal network operation

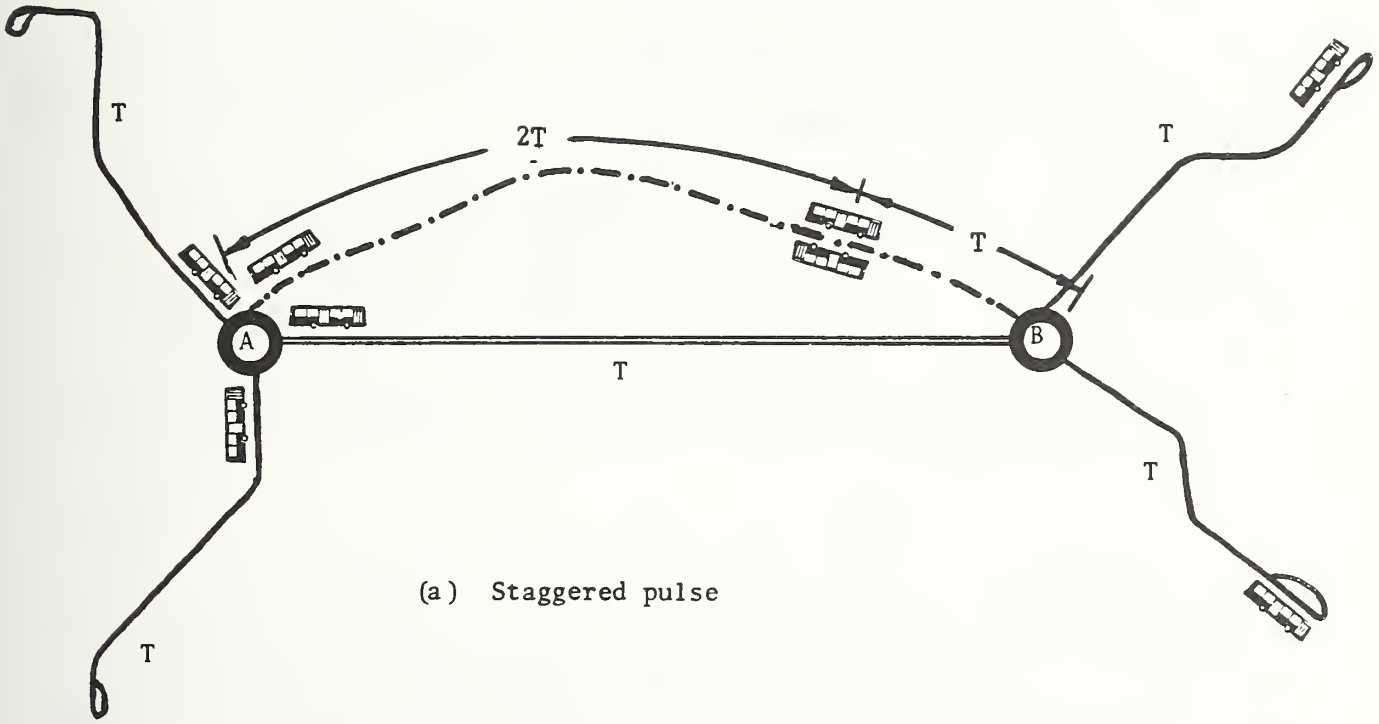
Case	Cycle times	Pulse	Direct connector	Radials	Collector-distributor	Figure reference
I	$T_d = T_r$	Staggered	h T N	h T N	h 3T 3N	4.7a
		Simultaneous	h 2T 2N	h 2T 2N	h 4T 4N	4.7b
II	$T_d = 0.5T_r$	Staggered	h T N	h 2T 2N	h 3T 3N	4.8a
		Simultaneous	h 2T 2N	h 4T 4N	h 4T 4N	4.8b
III	$T_d = 2T_r$	Simultaneous	h 2T 2N	h T N	h 4T 4N	4.9

In case I, $T_d = T_r$, both types of pulsing, staggered and simultaneous, can be operated. Since the headways on the connector, h_d, are equal to those on radials, h_r (basic assumption for full meetings during each pulse), the number of vehicles on the two types of routes is also equal, regardless of the pulse type :

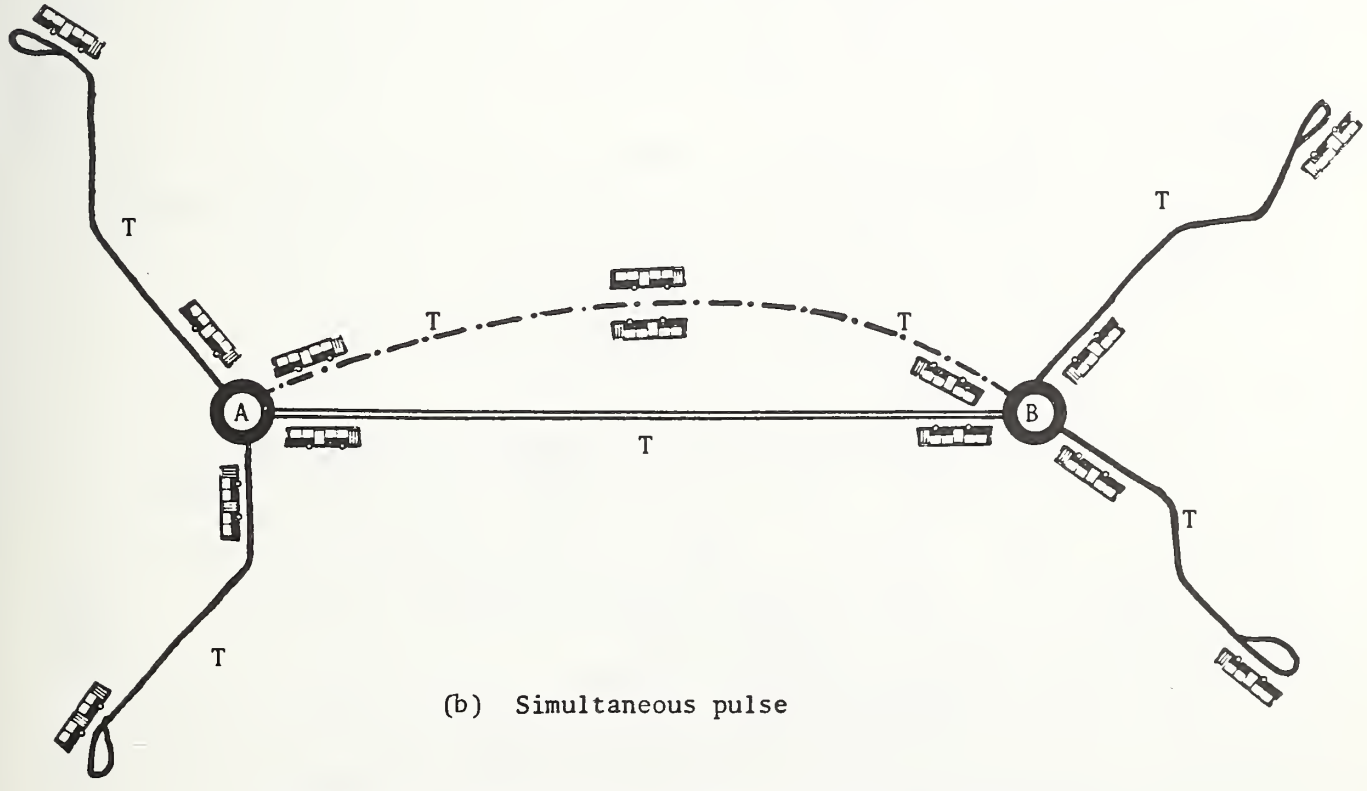
$$N_d = \frac{T_d}{h_d} = \frac{T_r}{h_r} = N_r . \tag{4.16}$$

A staggered-pulse schedule with $T_d = T_r$ can be operated with one vehicle on each route. Figure 4.7a illustrates such an operation at the moment terminal A is pulsing. The figure also shows that if a C-D connection is operated between the terminals A and B, the minimum cycle time on that route, T_{c-d}, which meets the requirements of the analyzed case is $3T_d$, and the minimum number of vehicles on it is:

$$N_{c-d} = 3T_d/h_p = 3. \tag{4.17}$$



(a) Staggered pulse



(b) Simultaneous pulse

Figure 4.7 Operations of a bifocal network with $T_d=T_r$

For a simultaneous-pulse schedule with $T_d = T_r$ each route must have at least two vehicles, since simultaneous pulsing at any two focal points requires an even number of vehicles (i.e. at least 2), and for full meetings at each focal point there must be $N_d = N_r$. For this operation cycle times on all routes are twice as long as the cycle times for the staggered pulse operation. If it is assumed that the round-trip speeds are the same, this implies further that route lengths are twice greater for the simultaneous than for staggered pulse operation.

C-D connector in this case has cycle times twice greater than the direct connector, or four times greater than cycle times on the direct connector and radials for staggered pulsing, which are used as the "basic operation" in this comparison (see Table 4.1).

In case II, $T_d = 0.5T_r$, the number of vehicles on radials is twice greater than on the direct connector:

$$N_r = 2N_d. \tag{4.18}$$

For staggered pulsing the direct connector has the same elements as in staggered pulsing of case I, but radials must have twice longer cycle and twice more vehicles. C-D connector has three times longer cycle and three times more vehicles than the direct connector. This operation is shown in Fig. 4.8a.

Figure 4.8b shows simultaneous pulsing in case II, in which the direct connector must have twice longer cycle and twice more vehicles than in the staggered case (i.e. 2T and 2N), while the radials and C-D connector must have 4T and 4N each.

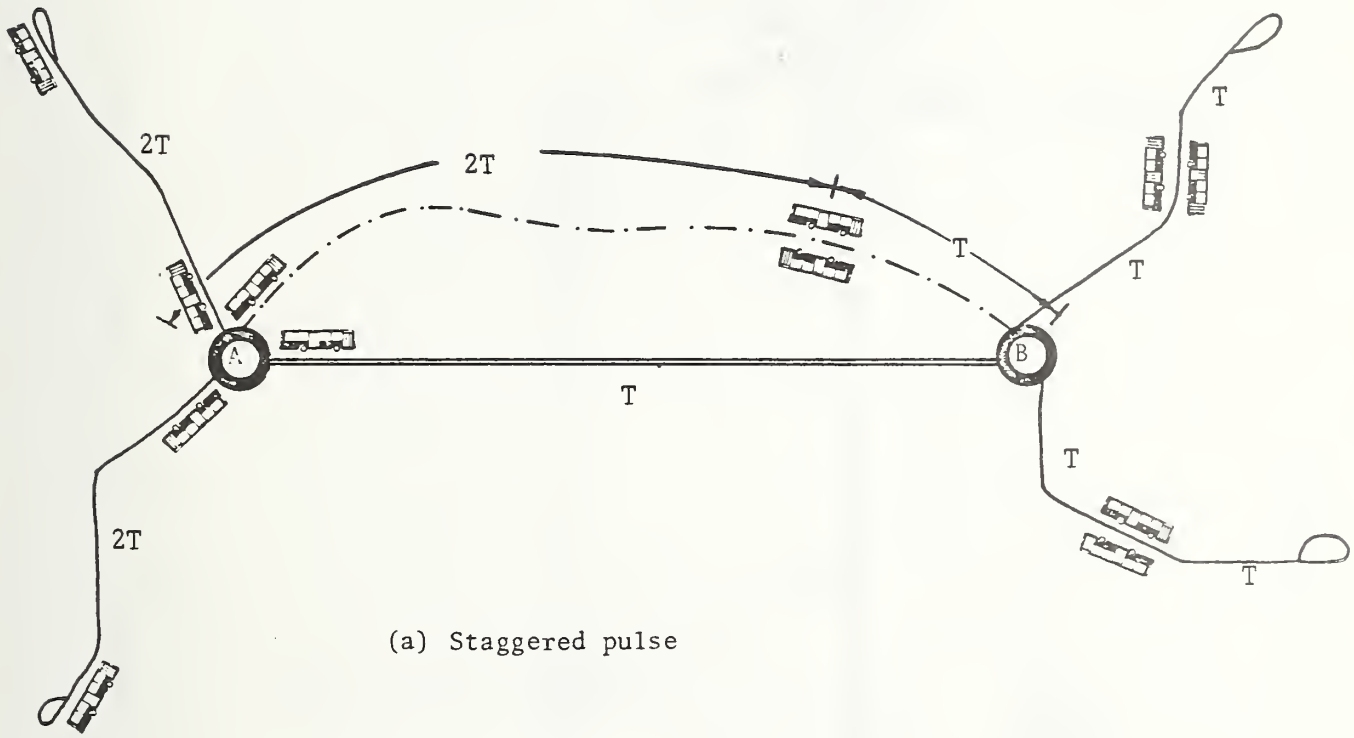
Finally, in case III $T_d = 2T_r$, so that $N_d = 2N_r$ and N_d must be an even number. Only simultaneous operation is possible, and with minimum operation the radials have only one vehicle each, direct connector has 2, and C-D connector must have 4. This operation is illustrated in Fig. 4.9.

All these values are systematically presented in Table 4.1.

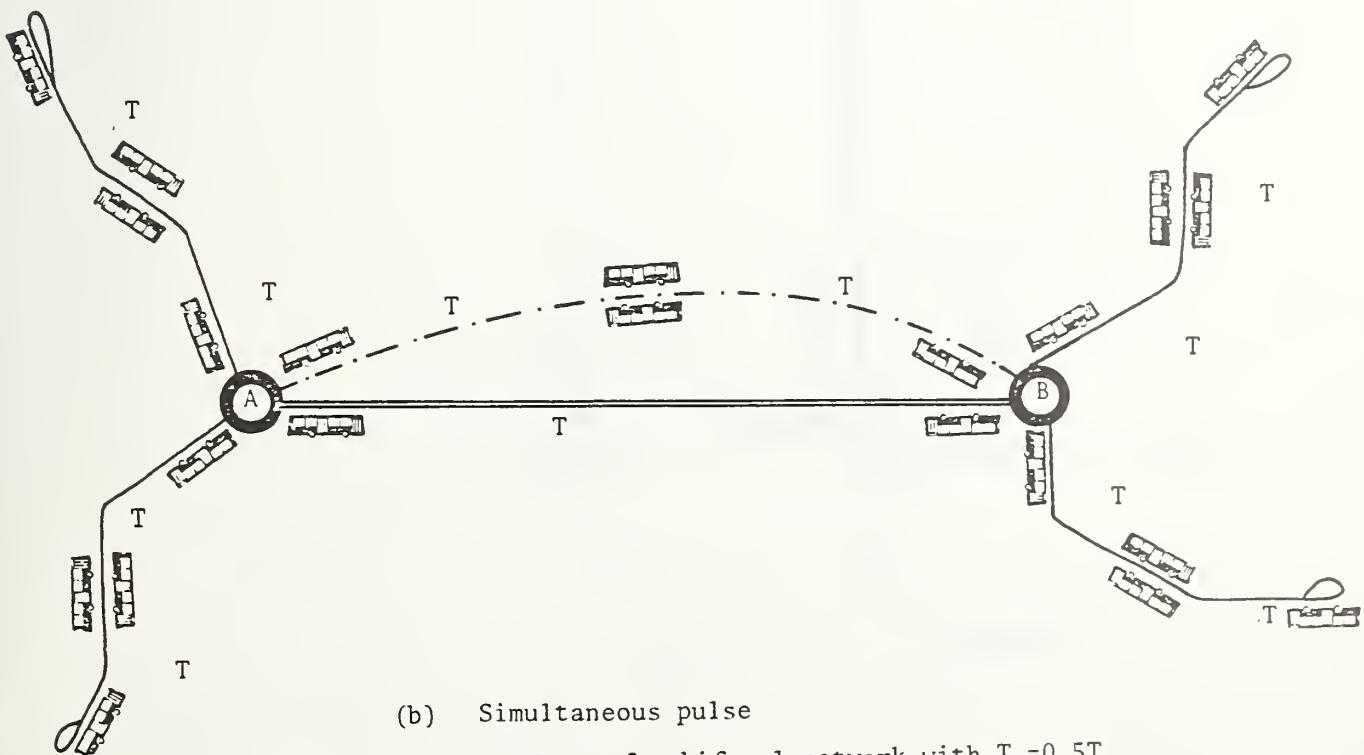
4.5 Types and Characteristics of Multifocal Networks

For large areas and extensive networks it is often necessary to have more than two focal points. There are many geometric forms of multifocal networks, but the basic ones are: linear or open, triangular, rectangular and polygonal. These larger networks introduce additional scheduling complexity, particularly for connector routes.

4.5.1 Linear Multifocal Networks. Linear type of network is formed when focal points are added "outward" from a bifocal network, as Fig. 4.10 shows. Relationships of operating elements in these networks are therefore similar to those in the bifocal network.



(a) Staggered pulse



(b) Simultaneous pulse

Figure 4.8 Operations of a bifocal network with $T_d=0.5T_r$

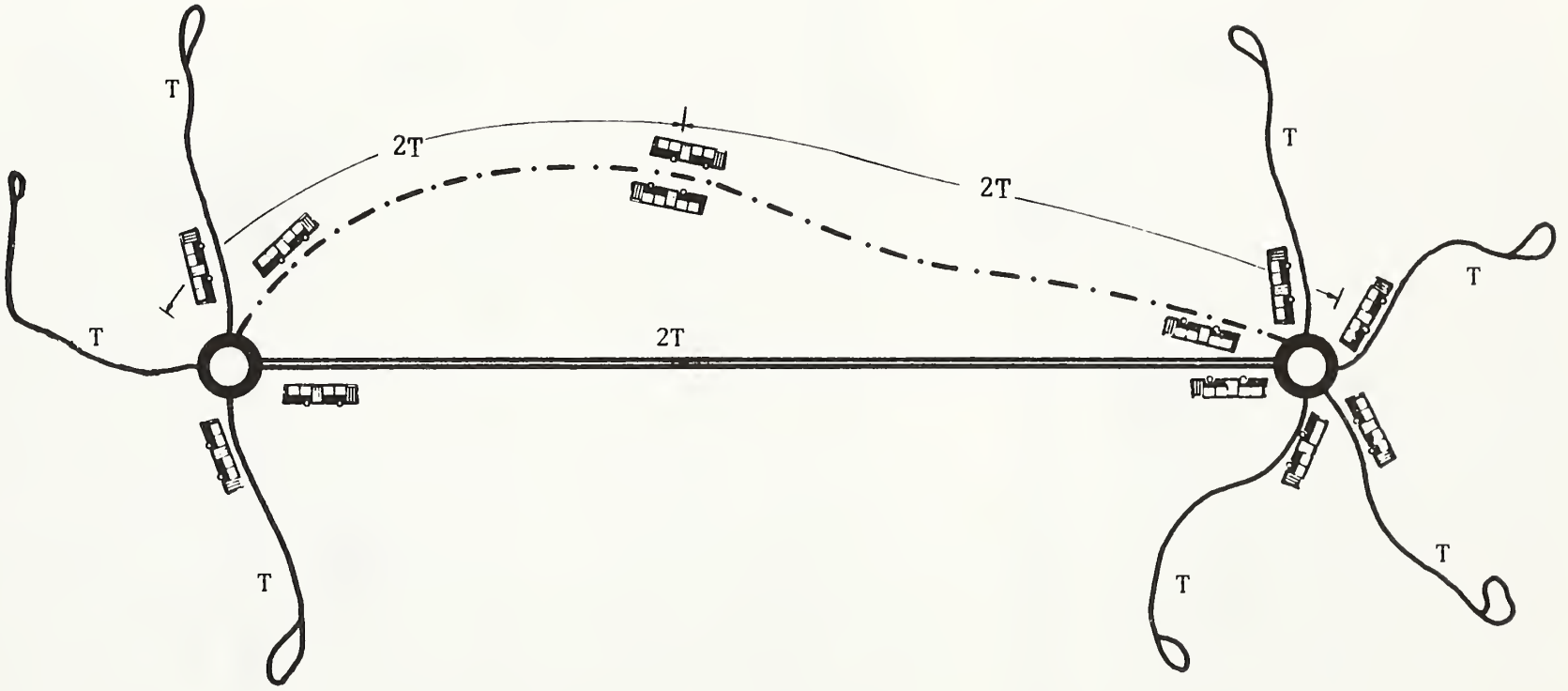


Figure 4.9 Operations of a bifocal network with $T_d=2T_r$ (simultaneous pulse)

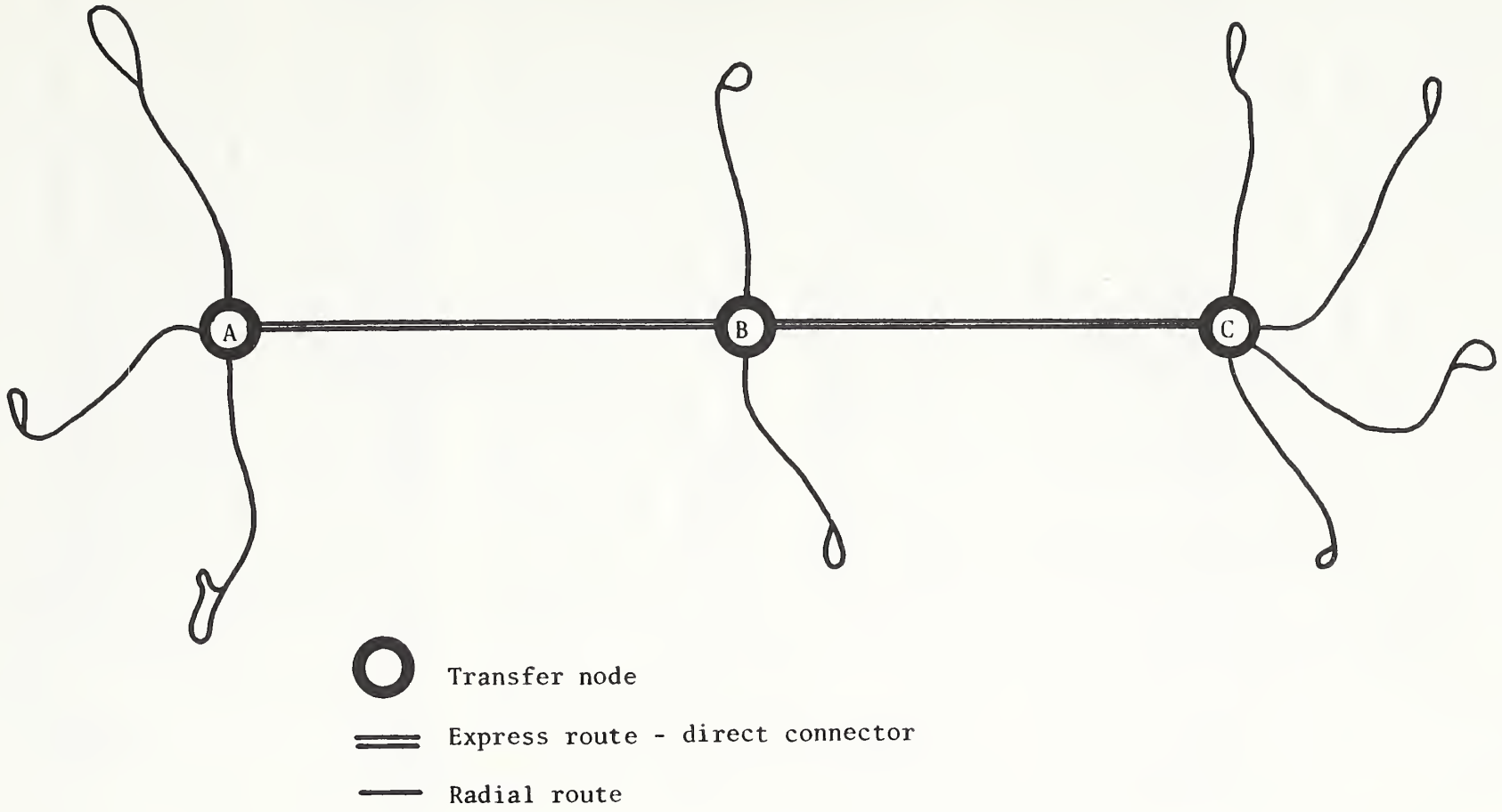


Figure 4.10 Linear multifocal TTS network

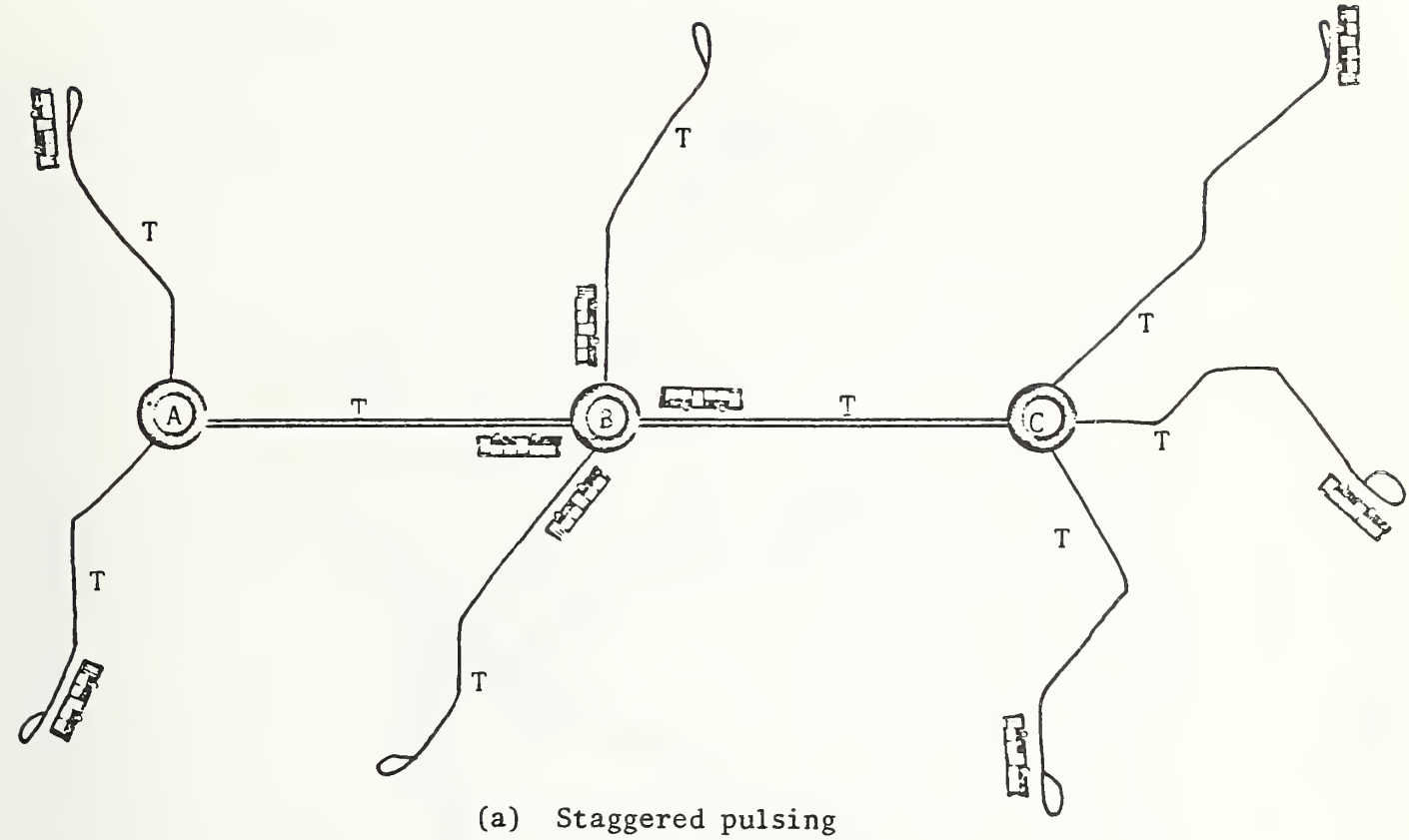
The basic linear TTS network, i.e. the one with the shortest spacings between focal points for a given basic headway and the minimum fleet size is again obtained by using staggered pulses. In a trifocal linear network (Figs. 4.10 and 4.11) terminals A and C would pulse simultaneously, while B would pulse T/2 time later. In a network with many terminals there would still be only two staggered pulses, each one being common for every other terminal. With such a staggered pulses operation, only one vehicle is needed for each direct connector route section between any two focal points, as Fig. 4.11(a) shows. For a simultaneous operation in the same type of network twice as many vehicles are needed for the direct connector routes, as the bus positions in Fig. 4.11(b) illustrate. At the moment shown in the figure each focal point is pulsing in all directions, and there is a bus at each outer terminal of radial routes.

As in the case of the bifocal network, both illustrated cases with multifocal networks each pulse represents a complete meeting of all routes serving the respective center. In other words, the analyzed cases insure that each passenger arriving to a center on one route can always transfer to any other route during the same pulse.

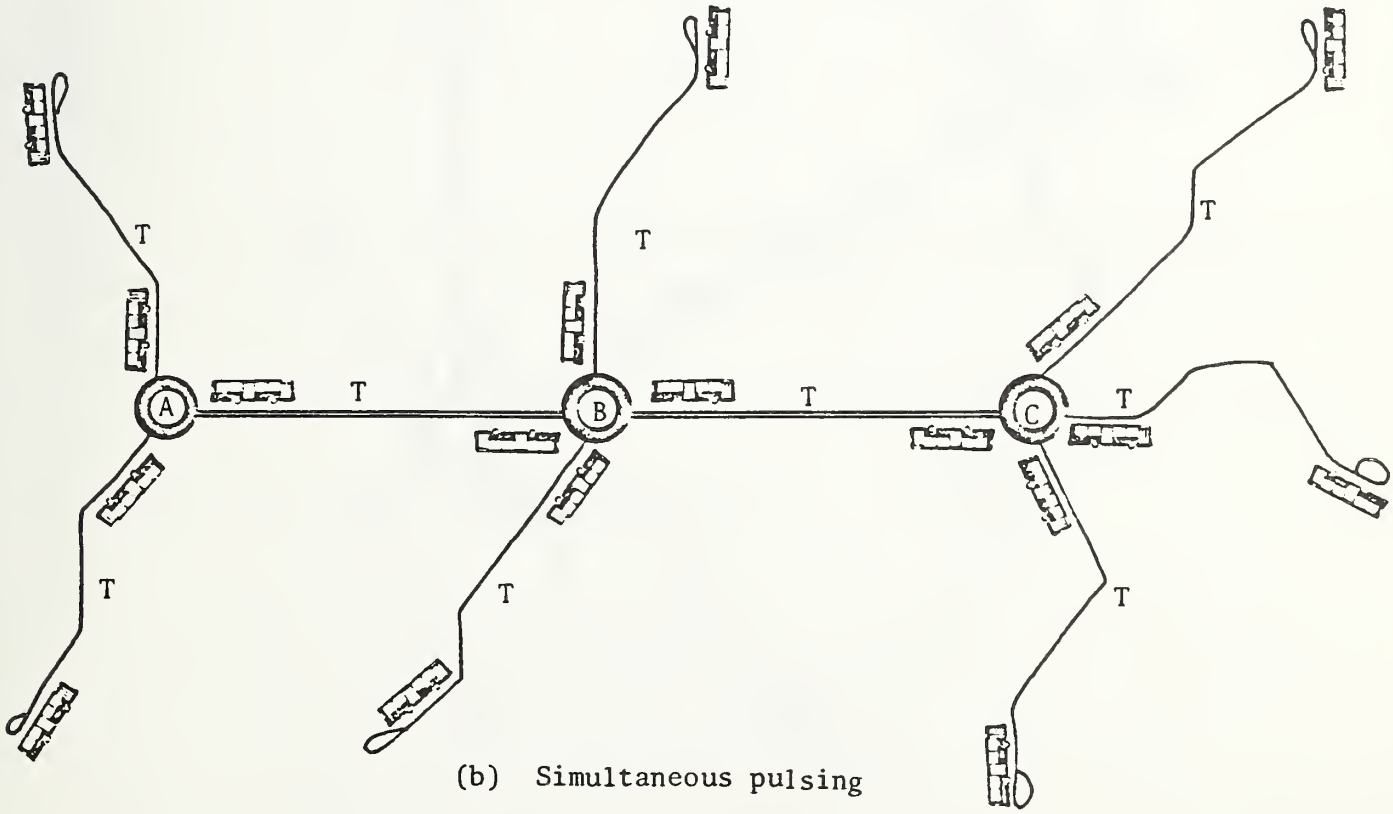
For open networks with more than three focal points and $T_d = T_r$ the relationships among operating elements remain the same. For a staggered pulse operation only one vehicle (bus) must be added for each connector route, and one for each radial route. Simultaneous operation two buses must be added for each connector, and two for each radial. In the cases where $T_d = 0.5\ T_r$ and $T_d = 2T_r$ the relationships again correspond to the respective ones for a trifocal network.

4.5.2 Triangular Networks. A triangular TTS network, shown in Figs. 4.12 and 4.13, forms a closed geometric pattern. The close interactions among focal points in this type of network place different constraints upon the operation of the connector routes.

In general, if each one of the three connector routes has the same cycle time T, a simultaneous pulse with two vehicles per route must be utilized, as shown in Fig. 4.12. Each radial route with cycle time T must also have two vehicles, while the radials with 0.5T need only one vehicle. The connector routes may be operated either as three separate ones, or as one continuous route, forming a two-way circular route.



(a) Staggered pulsing



(b) Simultaneous pulsing

Figure 4.11 Trifocal TTS networks with staggered and simultaneous pulses

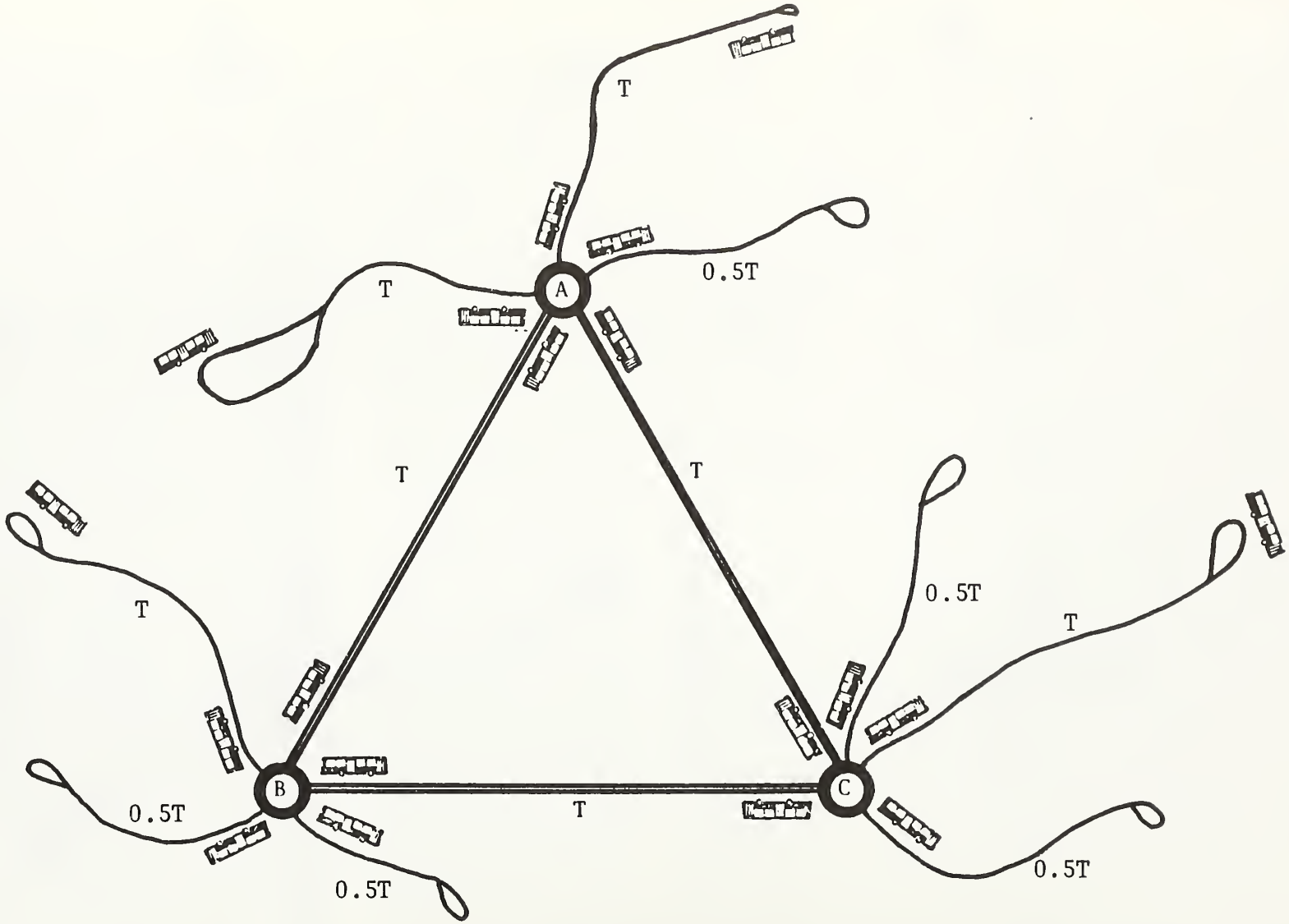


Figure 4.12 Triangular TTS network with simultaneous pulsing

A staggered pulse can be operated if one of the connector routes has a cycle time which is two times longer than cycle times on other connector routes. In such a network, shown in Fig. 4.13, terminal A pulses with the same headways, but half-cycle staggered from the pulses at B and C, which are simultaneous. Again, transfers among all connecting routes are provided for during each pulse.

The relationships among operating elements for a staggered and simultaneous triangular network are given in Table 4.2.

Table 4.2 Operating elements for a triangular network

	Radials	Route A-B	Route A-C	Route B-C
Staggered pulse	h T N	h T N	h T N	h 2T 2N
Simultaneous pulse	h 0.5T, T N, 2N	h T 2N	h T 2N	h T 2N

4.5.3 Rectangular Network. A TTS can also be organized in a rectangular geometric form, as shown in Fig. 4.14. This network also allows diagonal links which provide direct routes between non-adjacent focal points. As in the case of triangular networks, a simultaneous pulse must be operated when each leg of the connector route is exactly equal. If diagonal links are incorporated, they must be made to have the same T as other connector routes even though the physical distance is longer. A staggered pulse can be operated in a manner similar to that for the triangular network when one or two of the connecting segments has a cycle time twice longer than that of the remaining connector routes.

4.6 Comparison of Uni- with Multifocal Networks

The choice between unifocal and multifocal networks depends on the size of the service area and the desired level of service. In general, a multifocal TTS provides a better integrated network with more extensive area coverage, but has more complex operating requirements. More specifically, in comparison with unifocal networks, bifocal or multifocal networks offer the following advantages and disadvantages:

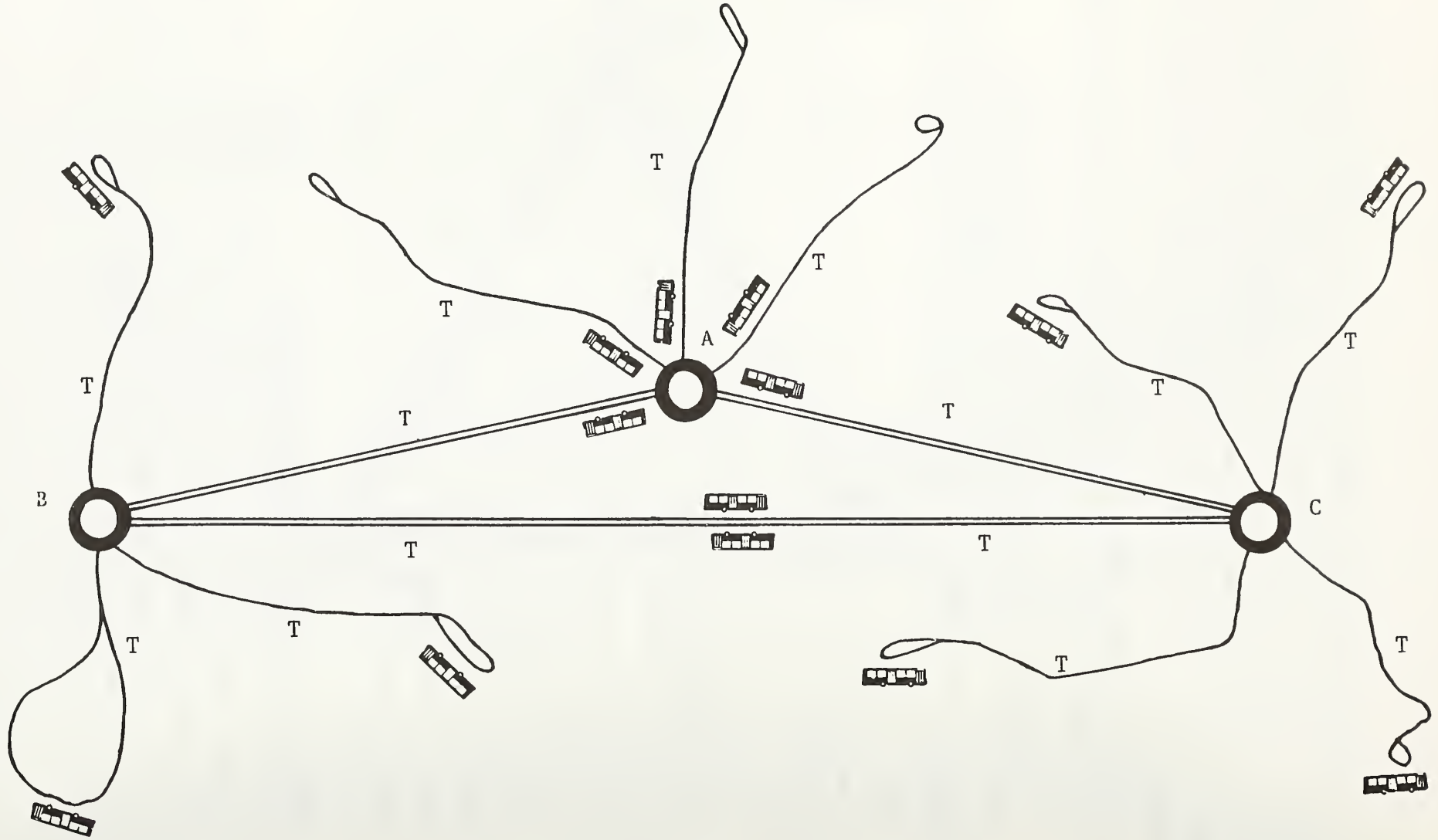


Figure 4.13 Triangular TTS network with staggered pulsing

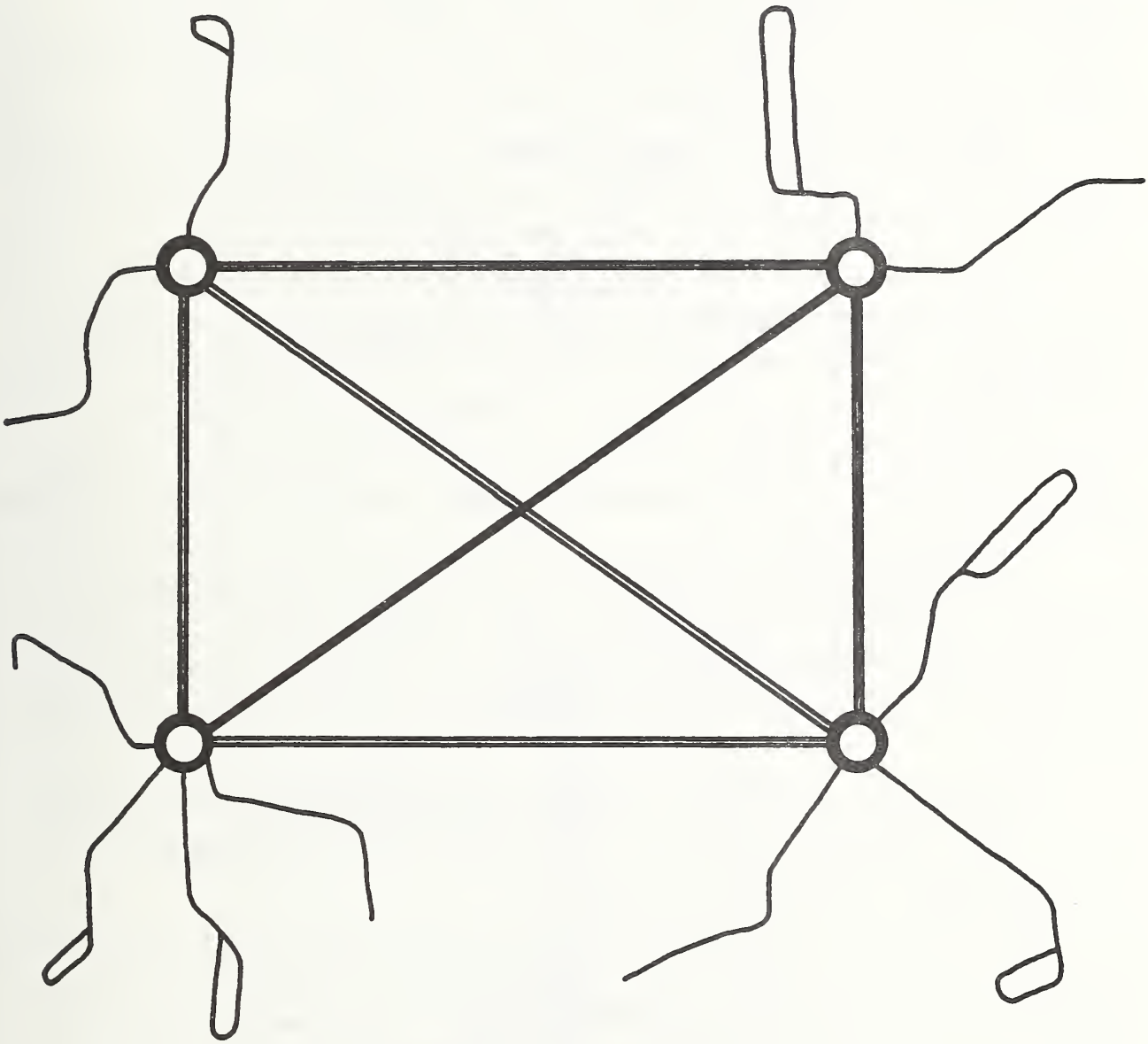


Figure 4.14 Rectangular multifocal TTS network

+ Area coverage is greatly expanded as more focal points are added to serve an area. Any service area encompassing a large territory would require more than one focal point if the whole system is to be included in the TTS.

+ Travel time can be shorter for many passengers in a multifocal TTS, especially for crosstown trips which are not radial into the focal point. This can be seen in Fig. 4.15, where the travel distance from A to B becomes significantly reduced by expanding to a bifocal network.

+ Additional important activity centers can be included as focal points.

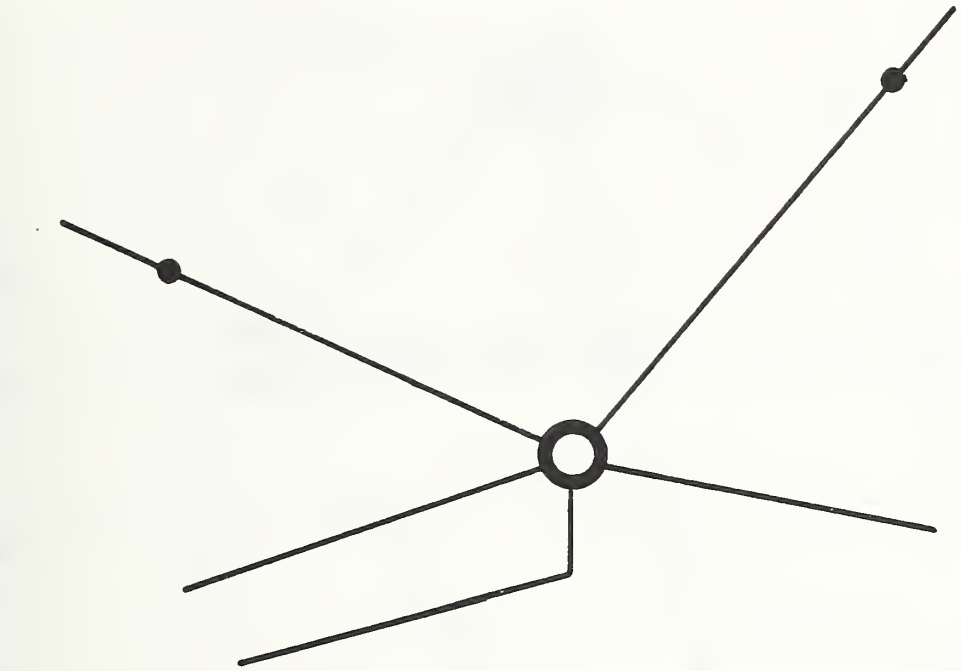
+ Potential congestion and capacity problems which may occur when all routes arrive at a single focal point are decreased or eliminated.

- For passengers who must travel through more than one focal point, the accumulated transfer time can become a significant portion of overall travel time. However, for most headways typically used in low density areas, this accumulated waiting time will still be less than the waiting time for uncoordinated transfers. Moreover, an attempt should be made to align routes so that only a small proportion of total passengers have to pass through two or more focal points.

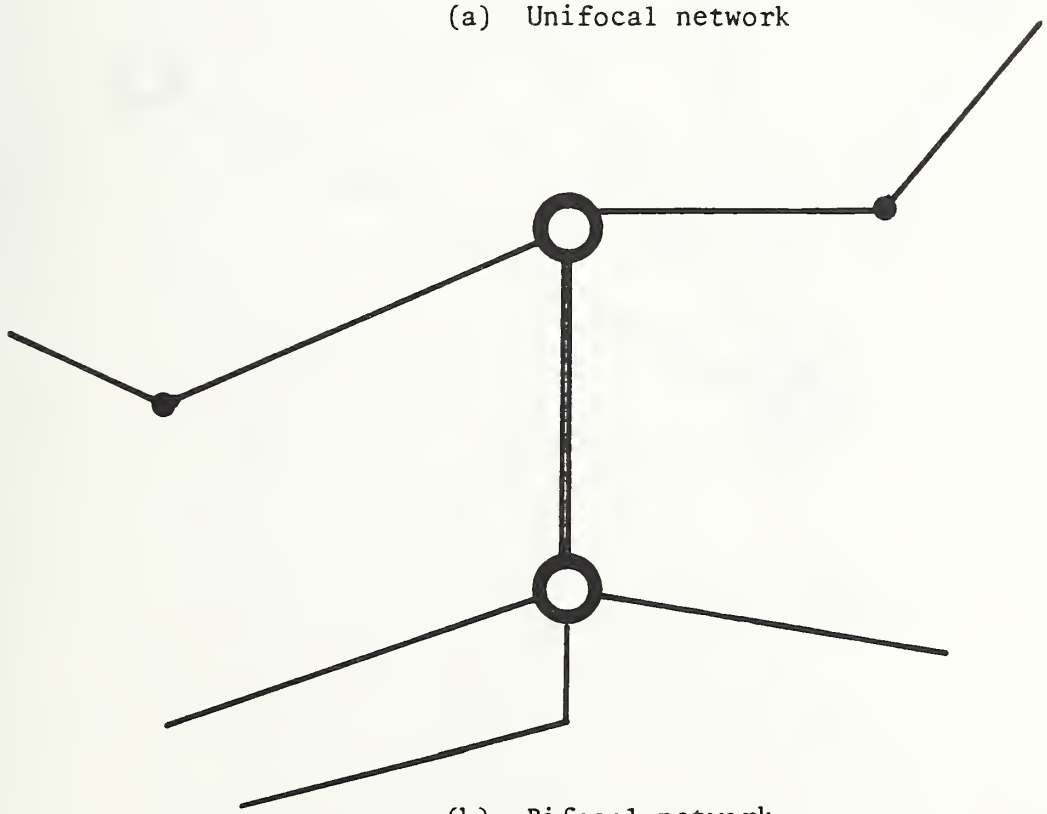
- Greater complexity of operation. More careful scheduling must be performed, particularly for connector routes. While a unifocal network may have different basic headways, depending on the area characteristics, a multifocal network must have the same basic h-L-V_c relationship throughout the network.

- Operations on a multifocal network are more sensitive because a delay on one route (especially a connector) can affect several focal points, i.e. it may propagate throughout the network.

Consequently, when choosing the number of focal points, the operator must analyze the trade-off between area-wide coverage with a multifocal network and simplicity of operation of the unifocal system. It is sometimes advantageous to develop a multifocal TTS gradually, so that additional focal points are included in the system after experience is gained with the operation of a simpler network. Generally, however, the decision of how many focal points a TTS network will have depends mostly on the size of the area which should be served. Unifocal networks are appropriate for areas of up to 4-6 km (3-4 miles), while larger areas require a multifocal interconnected network such as Fig. 4-16 shows.



(a) Unifocal network



(b) Bifocal network

Figure 4.15 Comparison of unifocal with bifocal TTS network

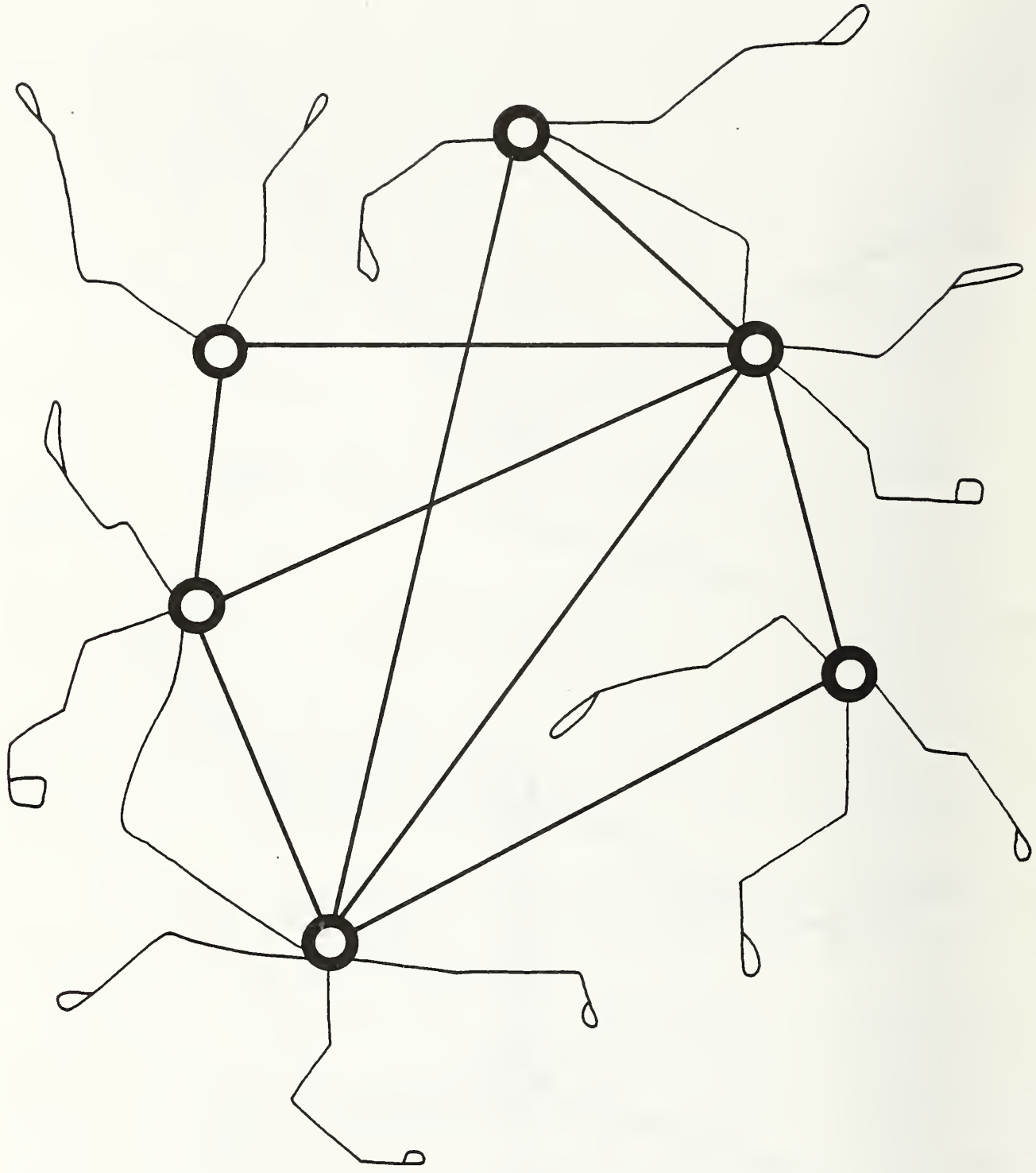


Figure 4.16 A multifocal interconnected TTS network

4.7 Transit Modes and Methods of Operations

TTS typically applies to transit routes with fixed schedules in low density areas. In most cases these are bus routes, but other modes can also be parts of a TTS. On one side of the regular bus mode (toward lower demand), various types of scheduled paratransit services, such as subscription buses or dial-a-ride, can be included in TTS. On the other side (heavily traveled lines), different forms of rail transit (light rail - LRT, rail rapid transit - RRT, or regional rail - RGR) can be the dominant components in some TTS networks.

4.7.1 Unimodal vs. Multimodal TTS Networks. Based on the number of modes used, TTS's can be classified into unimodal and multimodal types; each one has certain characteristic features.

Unimodal TTS networks tend to have rather uniform patronage and therefore similar service frequencies on all routes. Reliability of service is also rather uniform, allowing good scheduling compatibility.

The characteristics of buses allow a wide choice of transit center locations; however, these same features of buses - their flexibility and simple operations - may lead to the locations and design of very simple centers which are inconspicuous and have lower passenger attraction than large, specially designed off-street transit terminals.

Paratransit can use any type of bus transit center, but it may require specially designed area within the center, particularly if a significant number of paratransit vehicles is involved.

If rail transit exists or is planned for a TTS - served area, its stations are often prime candidates for transit centers. With their high speed, service reliability and capacity, rail modes can greatly enhance the usefulness of a TTS. LRT and RRT tie the entire TTS network into the larger city's transit system, while RGR often covers the entire region.

There are also physical conveniences in using rail stations as TTS focal points. First, rail stations are usually located at major junction points with good accessibility from many directions. And second, rail stations often already provide many of the auxiliary services and amenities that the focal points, or transit centers, should have.

In preparing an integrated bus/rail transfer station, consideration should be given to the frequency and character of rail line operations. If a rail line operates with long headways, which is the case with RGR and with all modes in the late evening and night periods, TTS is advantageous. Bus routes in such cases serve together with the rail service as a diversified, multi-purpose area-oriented network.

When rail line operates with short headways (typical for LRT and RRT during most daily hours) and bus routes serve predominantly as its feeders, TTS is not appropriate since it would cause uneven loadings of different trains. Therefore in some cases a "part-time TTS" can be used: bus arrivals at rail station are dispersed during the day when rail line has short headways, while in late evenings only train headways coincide with pulsing of bus routes.

When buses serve as feeders to rail and also carry passengers transferring among their routes, TTS has a purpose to facilitate these transfers. To reduce the phenomenon of uneven train loadings , bus routes can sometimes be divided into two or three groups, each one with routes among which transfers are substantial. This operation results in 2-3 "mini-pulses" which repeat themselves. They allow most transfers to be performed conveniently, and yet prevent excessively uneven loadings of trains. Figure 4.17 shows scheduling for such an operation. Arrivals and 5-min. terminal times are shown on an hourly, clock-shaped schedule. Buses from routes A, B and C arrive simultaneously every 30 min., while routes D, E and F form an alternate pulse staggered from the first one by 15 min. Rail line trains, not shown on the schedule, may arrive every 15 min., or with much shorter headways, such as 5, 4 or 3 min.

4.7.2 Review of Transit Center Operations. Based on the preceding discussions, operations at transit centers can be classified into three categories:

a. Staggered or irregular arrivals/departures on low-frequency routes;

b. Two or a few pulses of groups of routes; and

c. A single pulse in which vehicles on all routes arrive and depart at the same time.

Operation a is typical for many conventional operations with high frequency routes or complex networks with many transfer points. Each route can be independently scheduled according to its demand and operational characteristics. Stop locations can be used for more than one route.

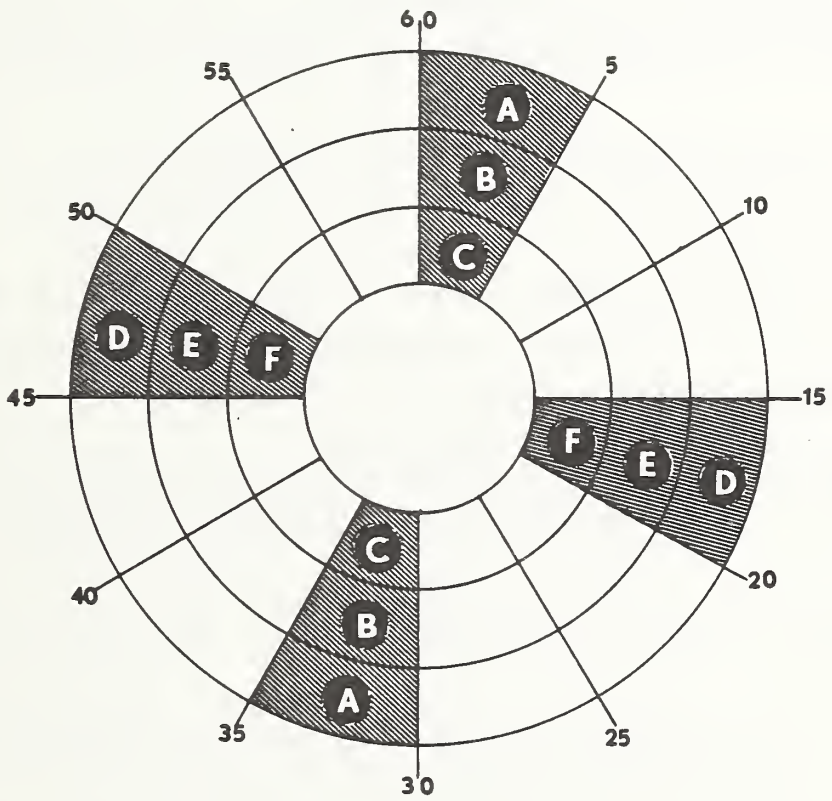


Figure 4.17 Clock schedule for a transit center with staggered pulses of two groups of routes

Operation b is a form of a TTS, although it does not have a single pulse. As described in section 4.7.1, this operation is used at contact points between high-frequency urban transit routes (typically rail) and sets of low-frequency suburban routes among which substantial transferring takes place.

Operation c, with a single pulse for all routes, is typical TTS which is most commonly used for low-frequency suburban routes with rather uniform transfering among all routes (as opposed to feeder/trunk relationship).

4.8 TTS Overview

4.8.1 Major Actions for TTS Implementation. Briefly stated, introduction of a TTS in place of an uncoordinated network involves the following implementation actions:

- Careful planning of the network and its operations;
- Provision of transit centers, which may vary from simple on-street bus stop locations to major off-street multimodal terminals;
- Changes in route alignments and/or schedules (cycle times, headways, etc.);
- Preparation and introduction of improved dispatching practices, information system and marketing activities.

4.8.2 Characteristics of TTS. Compared with conventional operation (a in section 4.7.2), TTS operation (c) has the following advantages (+) and disadvantages (-):

+ Transfers among all routes meeting at each transit center are much faster and more convenient;

+ Transit service represents a multidirectional, unified network serving a variety of trips, as opposed to services restricted to individual routes in networks without convenient transfers;

+ Large, distinct terminals provide a much greater number of services than small ones for individual routes;

+ Due to the better service (network, schedules, image, terminals), TTS attracts a substantially larger patronage and assumes a more important role than conventional networks;

- TTS generally requires a higher investment (terminals, information) and operating costs (more vehicles on routes), which may or may not be offset by higher revenues;

- Some passengers may have less direct routing and additional delays during layovers of through routes at transit centers;

- TTS is more vulnerable to delays: missed expected connections cause considerable aggravation of passengers;

- "Pulsing" at terminals may cause congestion on access routes and it requires large terminal capacities which are utilized only during short periods of time.

The operation b -- two or a few pulses -- falls in between a and c.

4.8.3 Applications of TTS. The decision whether or not TTS should be applied depends on the following major factors:

- Headway lengths: the longer the route headways are, the more is TTS applicable. For headways of 15 min. or longer, TTS usually has significant advantages;
- Volume of transferring: the more passengers transfer among routes, the more is TTS beneficial;
- Pattern of transfers: if passengers transfer among different routes, TTS is more important than if there is a feeder/trunk relationship, since the latter usually involves a trunk route with short headways;
- Need for tie-in of an important regional route (RGR, airport bus, express commuter bus) with all transit routes in an area;
- Service reliability: routes with very low reliability cannot be operated efficiently as a TTS.

Two extreme cases, one where TTS is very effective and the other where TTS does not apply will illustrate the influences of these factors:

1. A small town or a suburban area, with dispersed travel patterns and little street congestion, is served by a number of bus routes with long headways: TTS applies.

2. Central city with a dense network of routes operating at short headways: TTS offers no advantages and it is often physically impossible to organize it.

Section 5

TRANSIT CENTERS

Focal points of TTS networks, designated as "transit centers" or "transit terminals", represent the only infrastructure of a TTS itself (infrastructures of trolleybuses and rail lines which may be included in a TTS are parts of lines, rather than specifically of TTS operation). These facilities are permanent and efficiency of operation of the entire TTS depends very much on their design and operation. It is therefore important for the success of each TTS network to select locations and design its transit centers very carefully.

5.1 Selection of Locations

Transit center locations must be determined after consideration of the following major criteria.

1. Transit centers must lie in certain geometric relationships among themselves, so that TTS network can operate with joint headways, as described in section 4.

2. Locations must be such that they do not require rerouting and excessive additional travel of buses to approach them.

3. Adequate off-street area must be available for design of centers with efficient operation. Only in special cases on-street facilities (or a short street closed to other traffic) can be used.

4. Transit center locations should be convenient for pedestrian access. For this reason they often coincide with major activity centers, such as downtowns, shopping centers, long distance transportation terminals, major centers of business and other activities, etc.

5. As much as possible, transit centers should be away from arterials with heavy traffic volumes to avoid delays of transit vehicles traveling to and from them. At the same time, transit centers should be accessible to feeder modes, such as bicycles, taxis, kiss-and-ride automobiles and others.

6. Transit centers should be fitted in the surroundings with respect to their design and character. It is desirable that they have supporting facilities, such as shopping areas, office complexes, banks, post office, etc.

In summary, transit centers should be located at points served by several transit routes which fit geometrically in an efficiently operating TTS network. They should have an adequate area for all terminal activities; fast and convenient arrivals and departures of transit vehicles and safe, convenient and fast passenger transfers must be provided for; convenient pedestrian and feeder mode access should be available; at the same time they should be fitted well and insure mutual support of transit services with surrounding land uses and activities.

5.2 Classification and Characteristics

Focal points of TTS, or transit centers, can have a variety of physical forms. Small focal points, or the points at which a few bus lines meet and have a rather limited number of transferring passengers can be little more than a set of bus stops along a street curb. On the other end of the spectrum focal points of a TTS can be a specially designed multimodal off-street terminals with extensive facilities and services for passengers.

Transit centers can be classified into two basic categories: on-street and off-street facilities. As Schneider pointed out [4], each one of these can be divided into two types of terminals. On-street stops can be along the curb, or in specially designed bays or other curb forms; off-street transit centers may be sets of stops around one or several islands, or they can be elaborate multimodal transit terminals, sometimes with several levels and many passenger amenities.

5.2.1 On-Street Transit Centers. This category of TTS focal points requires rather low investment (only bus stop equipment with extensive information and, in some cases, reconstruction of the area where buses stop) and is easy to implement in a short time. However, on-street bus stops can have serious operational problems created by the friction between transit vehicles and street traffic. The transferring passengers often have to walk considerable distances along a linear set of stops. Finally, the image of this category of transit centers is rather weak. On-street transit centers therefore represent low-cost/low-quality facilities which are adequate for some locations (small number of routes, no street congestion), but inadequate for major TTS centers which should have an efficient operation and a distinct image.

Curb stops, shown in Fig. 5.1, are usually located along curbs away from one intersection corner, so that they are near-side stops on one street, far-side on the other (respectively stops A and B in the figure). With this design transferring passengers do not have to cross a street. If some stops must be located on the other side of the street, convenience and safety of transferring passengers must be given particular attention: designated crossings, signal protection and adequate information must be provided.

Curb bus stops for transit centers can offer a satisfactory operation only on the streets which have more than one lane per direction, and do not carry excessively heavy traffic volumes, and in towns which have strict police enforcement of traffic regulations.

Saw-tooth curb design for bus stops, shown in Fig. 5.2, can be used in some cases. This design for stops causes blocking of one traffic lane, similarly to the curb stops, and in addition it requires wider sidewalks so that the partial bays for buses can be accommodated. However, this type of bus stop has more identity than the simple curb stops. The main advantage of this design is that, because of easier access of buses to this form or curb, shorter curb length is required per bus stop. As the dimensions in Fig. 5.3 show, saw-tooth bus stops, which allow independent arrivals and departures of buses in each location, require approximately three meters shorter length per stopping location than curb bus stops which permit independent arrivals and departures.

Bus bays, shown in Fig. 5.4, are extensively used for bus stops on streets in many countries. Their main advantage is that they do not block traffic lanes, but their shortcoming is the problem of re-entry of buses into traffic lanes after they had stopped in the bay. They should therefore be used only at locations where bus re-entry can be secured by various traffic control devices, by extending the bay into an intersection and providing an advanced signal for the bus, or by other measures.

As the designs and dimensions of bus bays in Fig. 5.5 show, bays require longer length than saw-tooth bays, but the fact that they do not impede traffic lanes makes them feasible for use even along streets with only one lane per direction.

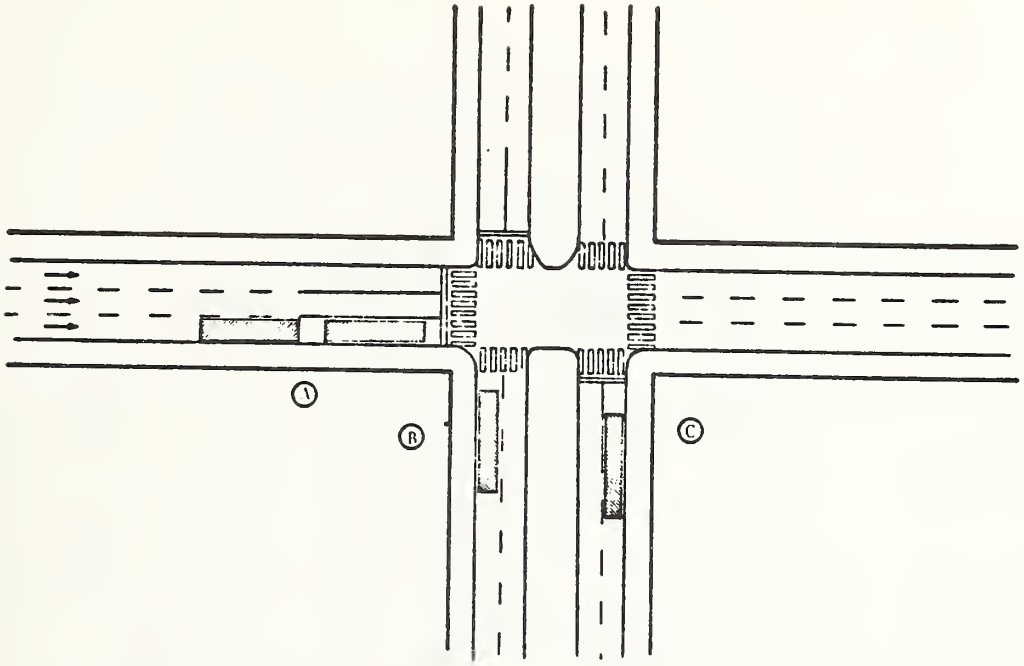


Figure 5.1 On-street transit center with curb stops

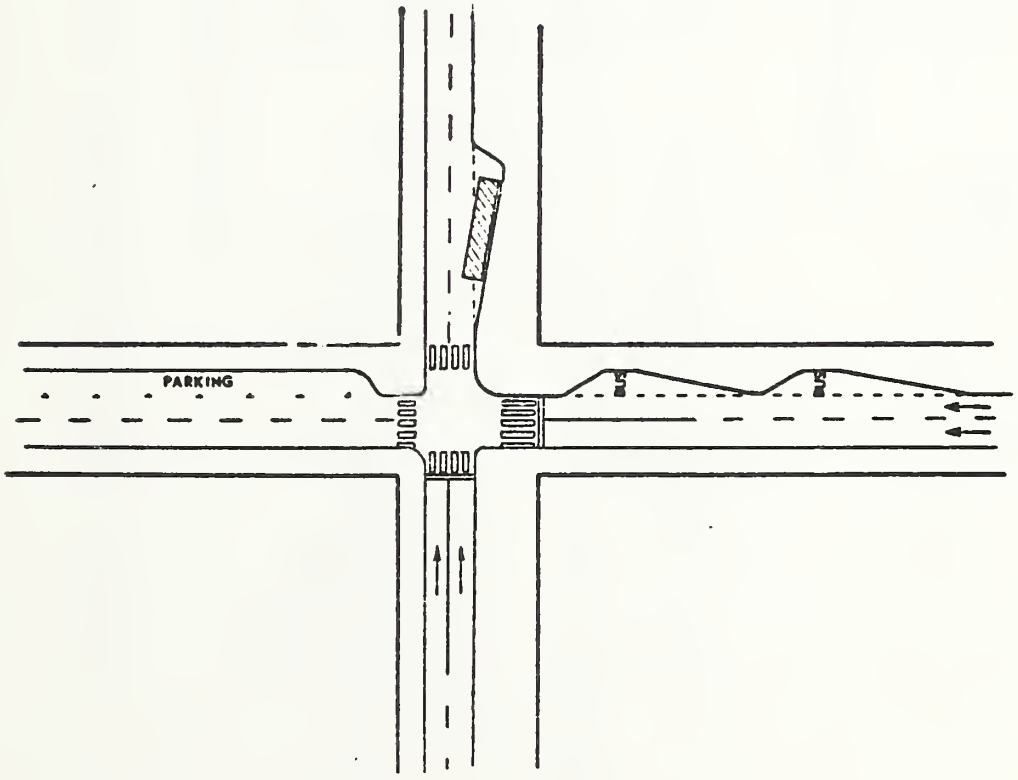


Figure 5.2 Sawtooth design of bus stops on street

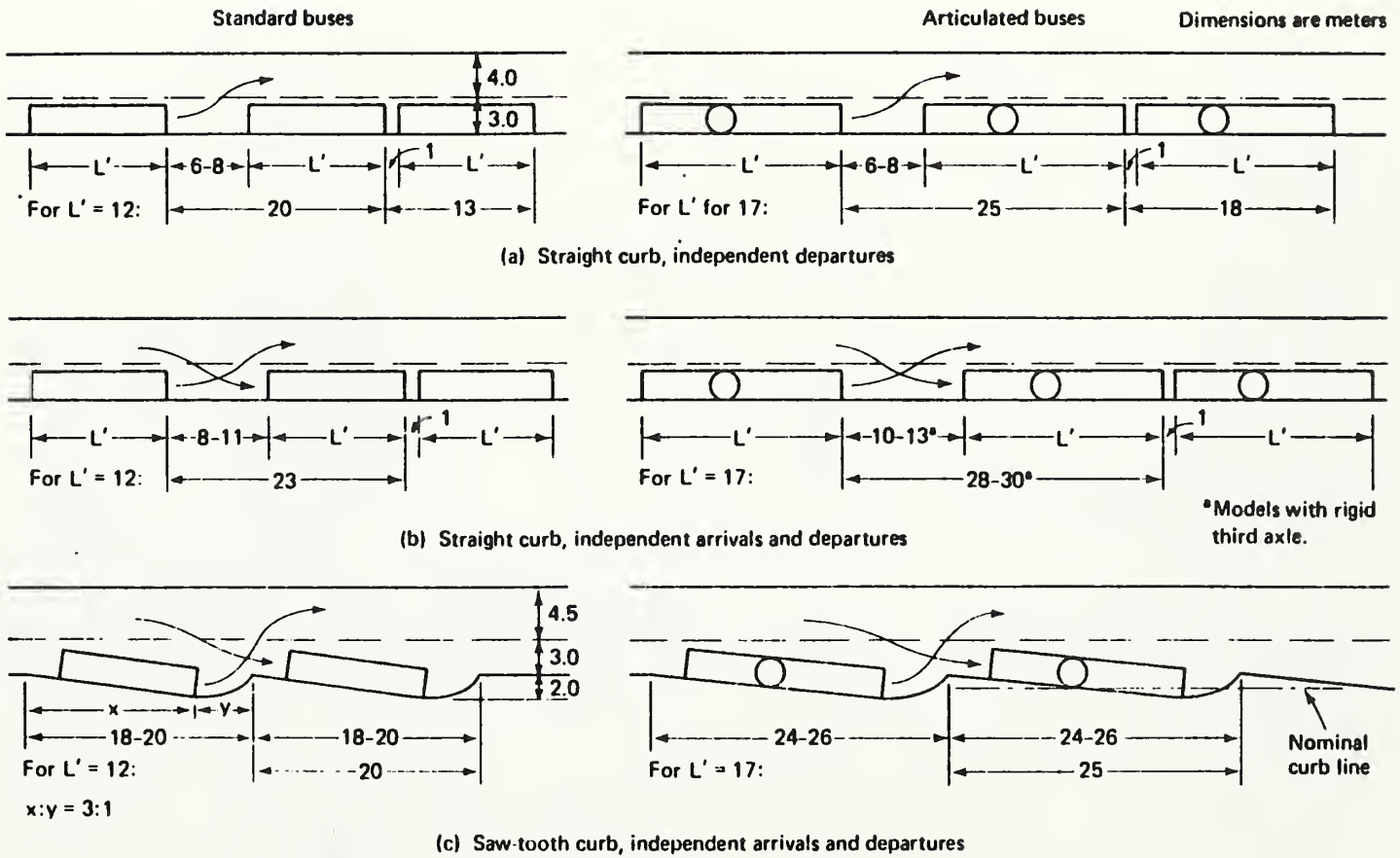


Figure 5.3 Dimensions of different types of curb bus stops

Source: [10]

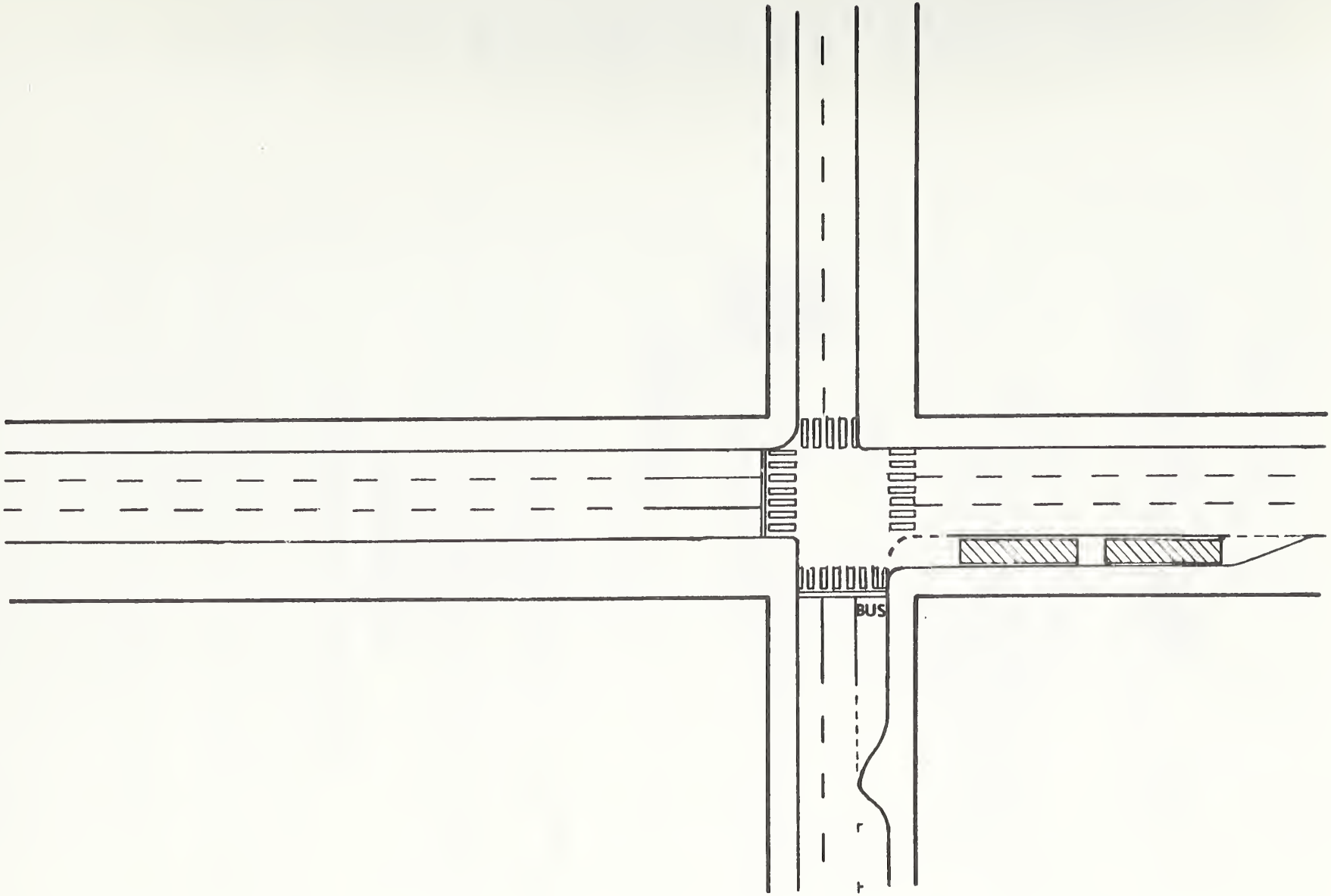


Figure 5.4 Bus bays for on-street stops

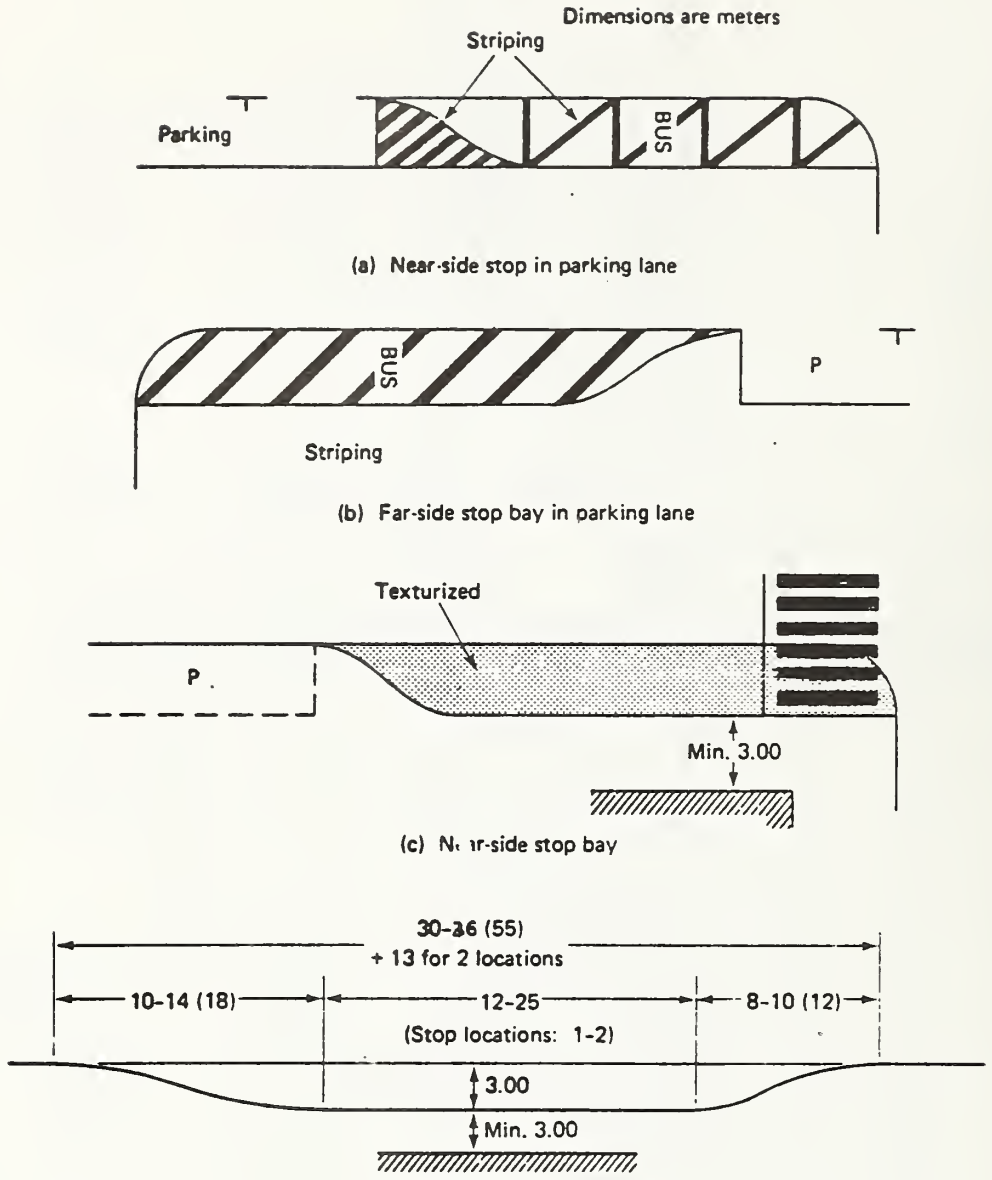


Figure 5.5 Design details and dimensions of bus bays

Source: [10]

5.2.2 Off-Street Transit Centers. Wherever land can be found and local conditions permit, off-street facilities should be built for transit centers. This type of facilities eliminates interference between transit vehicles, passenger movements and street traffic; the area can be fully controlled, so that all terminal operations can be performed reliably and conveniently; finally, the image that these facilities have is far better than the image of on-street facilities.

As already mentioned in section 5.1, locations of off-street transit centers should be selected so that their access by transit vehicles, pedestrians and any feeder vehicles is easy and not interfered by heavy traffic. Other desirable features of these centers which must be considered in their design are as follows:

- If entrances and exits of transit centers are on two-way streets, it should be possible for transit vehicles to turn into and out of them from both directions, so that any transit vehicle coming from either direction, can continue in the opposite direction or return to the direction it came from after leaving the center.

- In most cases turning transit vehicles around is desirable for easy reassignment of vehicles between routes, pulling them out or placing them back into service, etc.

- One or more locations for waiting vehicles should be provided to allow storage of vehicles which either wait for their schedules, serve as replacement reserve vehicles, or wait for minor repairs.

- It is desirable that large volumes of transferring passengers do not cross roadways; this is achieved by "central island" type designs; however, if the number of buses is not great and visibility is good, it is possible to allow passengers to cross roadways.

- In major bus stations with heavy flows transferring into rail transit stations, it is always desirable to provide direct paths from all bus stop locations into the entrance of rail stations without crossing any traffic lanes.

Two simple designs of transit centers are shown schematically in Fig. 5.6. The design (a) is an "island type", but it does not allow internal

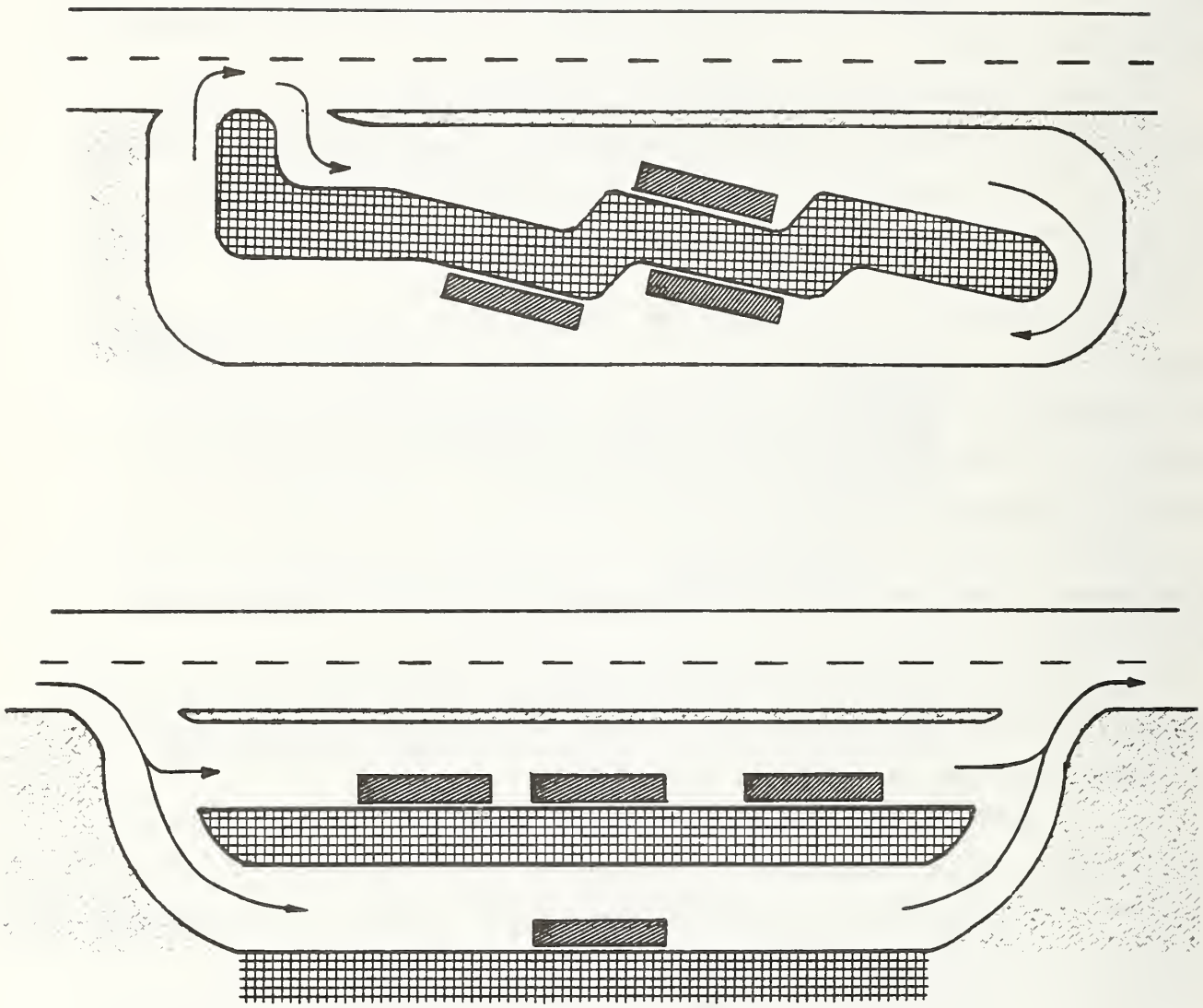


Figure 5.6 Medium-size off-street bus transit centers

circulation of transit vehicles because of limited space. Design (b) is with one-way flow and two parallel platforms which requires that passengers cross one roadway between those platforms. This design is adequate only in the cases in which transit center is on a one-way street and has low to moderate bus volumes.

A station with parallel islands for bus stops and a grade separated connector to a rapid transit station is shown in Fig. 5.7 (a). The following figure, (b), represents the highest type facility: all buses go around an island and all passenger movements can be done without intersecting any bus roadway. Entrance into the rapid transit station is from the central island.

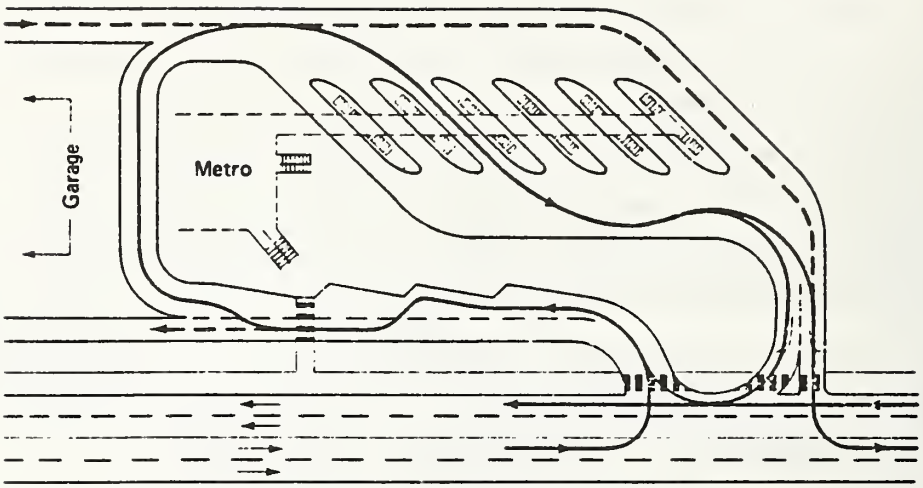
5.3 Design and Operating Elements

A detailed analysis of future operations should precede design of every transit center. Some major elements which should be considered are discussed here briefly.

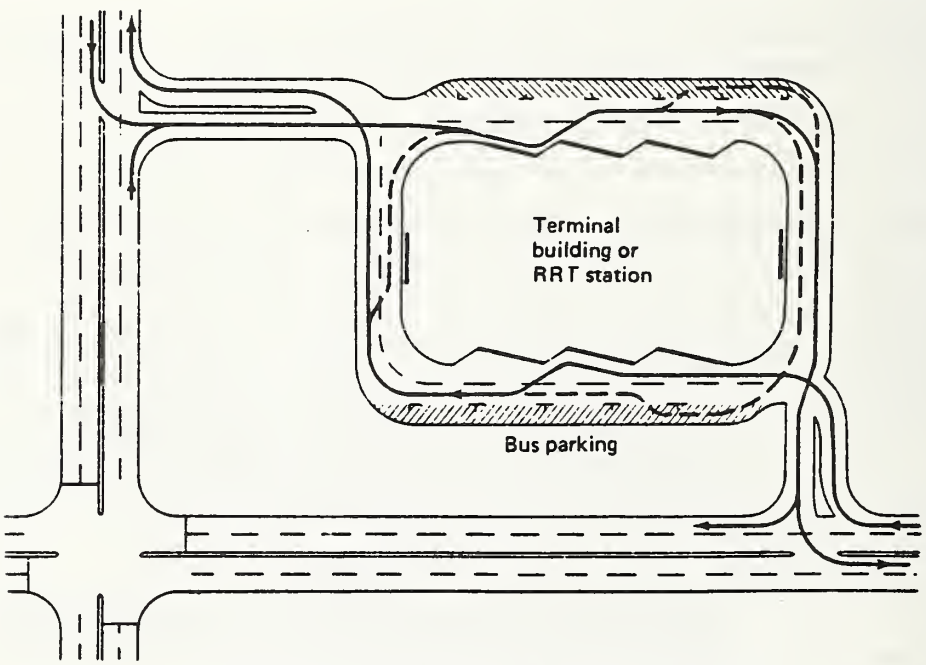
Terminal capacity, in terms of the number of bus stop locations, is rather simple to determine. While for many transit stops an analysis of arrivals, duration of standing, irregularities in service, etc. must be analyzed, in the case of TTS operation it is exactly known how many transit vehicles always arrive simultaneously. If the headways are long (10 minutes or more), which is typical for TTS, there would not be any interference between vehicles of successive pulses on the same line. Thus, the number of locations is simply computed as the number of lines which will arrive simultaneously to the center, plus any reserves for future expansion, plus standing locations for reserve or waiting vehicles.

Vehicle size is particularly important with respect to the distinction between standard and articulated buses. If the distribution between these two types in future operation is unknown, it is advisable to adopt a straight curb rather than saw-tooth design since the latter has very different dimensions for the two types of bus vehicles and allows no modifications short of total reconstruction.

Transferring directions of passengers should be considered from the projected demand for transferring between routes. The routes which have the largest volumes of transfers with other routes should be placed in



(a) Bus-rail transfer station with island stops



(b) Central island station in quadrant of an intersection

Figure 5.7 Major off-street bus stops with transfers to rail transit

Source: [10]

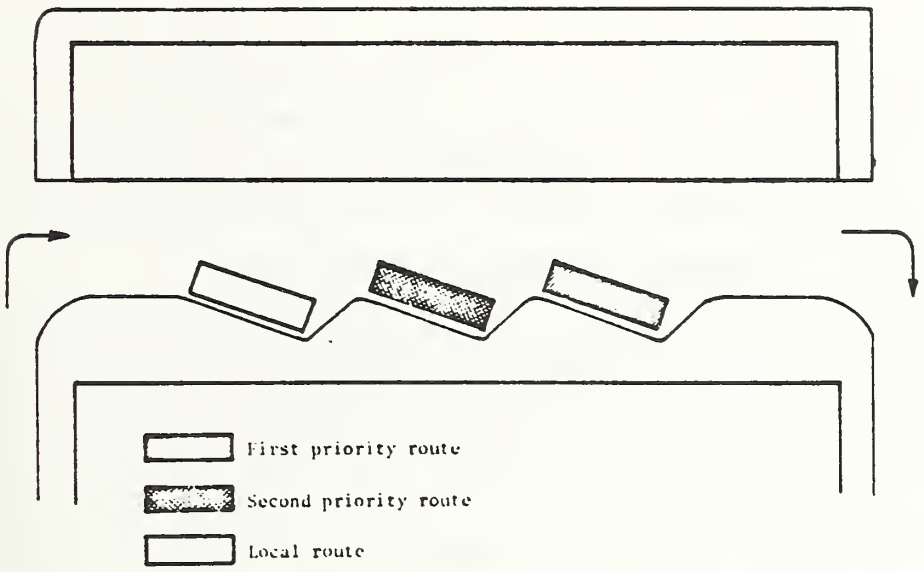


Figure 5.8 Priority locations for different bus routes

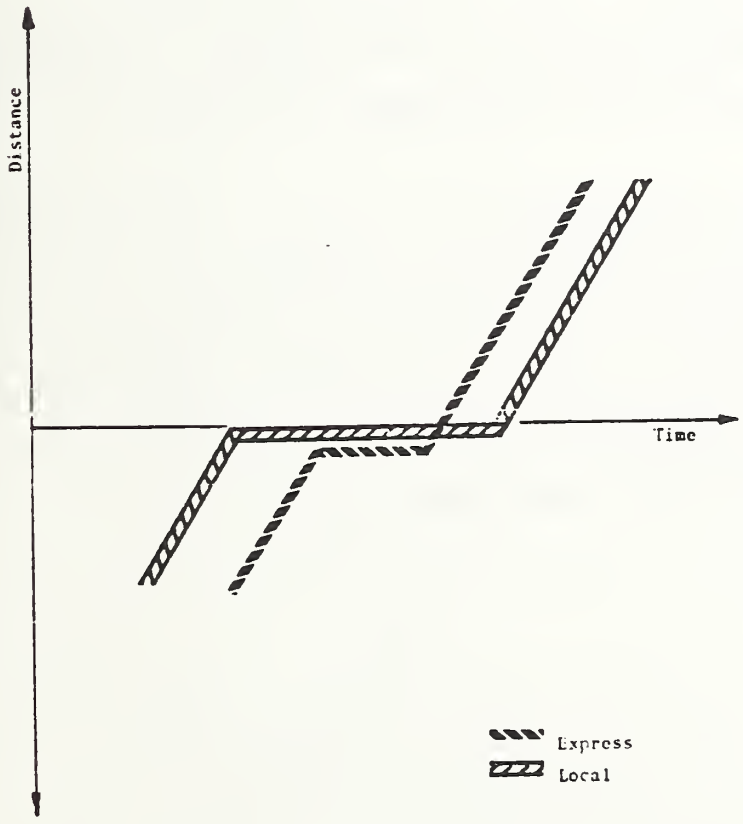


Figure 5.9 Arrival-departure sequence for local and express transit routes at a transit center

central locations, i.e., at "centers of gravity" in any design of transit centers. Routes which have very light transfers among themselves can be located at the most remote locations from each other. In this planning it is important to consider both directions of transferring, particularly the situations during the morning and afternoon peak hours.

Express and local routes should also be planned carefully. In many cases a number of local routes terminate at a transit center, while one or more routes arrive from one direction, stop at the center and continue as express or direct connectors to other centers. These expresses should be given priority locations (see Fig. 5.8) so that they can arrive and depart with minimum interference. This type of arrangement will allow the operation in which local routes have schedules with longer dwell times at the center than the express route. Thus the locals first arrive, the express arrives and departs after that, and finally the locals depart to their respective directions. This type of operation is illustrated on a time-distance diagram in Fig. 5.9.

Passenger services should be provided at all major transit centers. These include such facilities as fare collection equipment, information, waiting rooms, rest rooms, telephones, newsstands, and eventually even snack bars or various shops.

In addition to these specific requirements for transit centers necessitated by the character of their operation, the designers of these facilities must be familiar with many other technical and operational details of transit terminals in general. Further information on these elements can be found in Refs. [8 and 10] for the design of physical elements and in Reference [5] for extensive description of numerous transit centers, particularly those developed for TTS operation in recent years.

Section 6

TTS PLANNING AND DESIGN PROCEDURE

Based upon the description of TTS and its operational characteristics given in the preceding sections, a complete procedure for the planning process of TTS will be presented here. While some variations in the process exist due to differences in local conditions, a sequence of major steps to be followed in most cases can be defined.

Somewhat different procedures for TTS planning can be described for two different cases:

- An existing, conventional transit network is to be converted into a TTS; and
- An entirely new TTS is to be introduced into an area.

The differences between the two cases stem mostly from the fact that in the former case considerable data about transit usage exist, while in the latter case there is no experience with transit operations so that planning must be based entirely on projections.

6.1 Initial Steps

Beginning with the first considerations of introducing TTS into an area, general planning steps can be defined as follows.

6.1.1 Decision to Use TTS. The first, basic decision which must be made is whether TTS should be used. This decision must be based on an analysis of the effectiveness of a TTS system as compared to the conventional transit system. The conditions which favor adoption of a TTS, analyzed in sections 3 and 4, are summarized here:

- The area's travel demand is characterized by dispersed O-D patterns (many-to-many);
- Demand density is rather uniform and major trip generators are located at several locations dispersed throughout the areas, with moderate concentrations at each one. This results in the demand for transit routes with rather similar headways converging on several different nodes;
- Headways are long ($\geq$ 15 min), making transferring difficult and inconvenient for a conventional transit network.

In areas with conditions like these an initial evaluation will show whether a TTS is superior to conventional transit operation. If the evaluation is positive, TTS planning proceeds.

6.1.2 Definition of the Service Area. In planning a TTS it is necessary to make initially a general delineation of the area to be served by the TTS network. For an existing transit system the service area is usually similar to the one already served (unless major changes in the extent of transit service are planned). For new services in an area its extent depends on area characteristics and on the decision of what level-of-service (quantity and quality) should be offered. Adoption of policy level-of-service standards related to population or trip generation density is useful in determining the extent of the service area and thus extensiveness of the new transit network.

6.1.3 Collection of Data. An important step during the initial planning of TTS is the collection and analysis of all pertinent data. In planning a TTS, the important data and information include land use patterns, population size and density for the served area, major present and planned developments, shopping, residential or office complexes, factories, recreational centers, etc.), street network, traffic conditions and, specifically, travel speeds on streets at different times of the day.

Much of this information can be derived from origin-destination studies which encompass all modes, including automobile and transit trips. These studies are often performed by the local planning agency (in larger cities, MPO). If there is already an existing transit service in the area, data such as ridership (total and by route), trends in recent years, peaking characteristics, transfers, reliability of services, operating elements of existing routes (speed, length, cycle time) and number and types of vehicles in the fleet should be collected.

6.2 Preliminary Planning of Network and Operations

Once a TTS network is found to be advantageous for the service area, preliminary sketch form of the network can be defined. This will indicate the overall pattern and orientation of the system from which more detailed analysis can be carried out. The items which should be analyzed are:

- potential locations for transit centers;
- route alignments;
- operations.

6.2.1 Potential Locations for Transit Centers. As a first step, a number of feasible potential locations for transit centers in the service area should be identified. As stated in section 5.1, these locations should desirably, meet the following requirements:

- They should be in certain geometric relationship among themselves, rather evenly distributed throughout the service area;
- Each location should be at an intersection of several transit routes and, preferably, at a place with considerable transit demand;
- Each location should have an adequate off-street area easily accessible by buses, but away from congested traffic arterials;
- Good physical/environmental "fitting" of centers with their surroundings should be possible.

Since local conditions vary among the potential transit center locations, it is unlikely that all initially examined locations will meet all the requirements. Obviously, unsuitable ones should be eliminated from further considerations, but those which reasonably satisfy most requirements should be retained at this stage to allow a greater choice in further network and operations planning.

6.2.2 Route Analysis and Planning. This phase of the planning process should identify layout and characteristics of each route to be included in the TTS network. In reorganizing existing services, present routes are examined; in planning a new TTS, new routes are laid out considering travel desire lines, characteristics of corridors and street network pattern.

After identifying the route sections which should be included in the TTS network, each route should be broken down into its fixed and optional sections. A fixed section is where high transit demand levels definitely require scheduled transit service. Major highways often represent corridors which require transit service. Along with these transit corridors, individual locations such as shopping centers, large apartment or office complexes and other major traffic generators can require transit service because of their high transit trip generation.

Optional sections are those which are operated to increase area coverage, but are not absolutely vital in consideration of demand factors. Examples of optional sections are mid-route diversions and outer ends of routes in low density areas. These sections can be added to or deleted from a route with relatively little impact on the level-of-service. The identification of optional sections is an especially important task in TTS planning because the requirement for uniform (or multiple) cycle times often requires adjustments in route lengths. If adjustments are found to be necessary (see section 4.3.3), they should be made on the optional sections of a route.

An analysis should also be carried out assessing the street and traffic conditions along each route. Ideally, each route should operate over streets and highways which are free of congestion and form the most direct link between two points. Consideration should also be given to operational factors such as one-way streets, adequate turning radii for buses at intersections and sufficient clearances.

The final aspect of route analysis is whether routes should be radial or diametrical through the transit center. This is done by analyzing each route segment and determining whether route segments on different sides of the transit center have:

- similar demand characteristics, so that both require the same headway;
- many trips through the transit center.

If both these conditions are met, two radial segments should be combined to form a through or diametrical route.

6.2.3 Operations Analyses. After the analysis of route alignments and characteristics, operating elements (primarily headway - h, round-trip speed - V_c, cycle time - T and number of vehicles on a route - N) must be included in further planning. All these elements must be selected so that, together with route lengths - L, they form relationships for the selected network type, as defined in section 4.

The basic decision in this planning phase is the selection of the basic pulse headway - h_p. For the reasons described in section 4.3, the choice is in most cases between only two values of the basic policy headway and their multiples:

a. 15, 30 and 60 minutes; and

b. 20, 40 and 60 minutes.

The one which is closer to the ideal headway for each route individually (preferably the same or slightly longer) should be selected.

The selected pulse headway determines the travel time module between centers, which can be translated into distance L via round-trip speeds V_c. Multiples of this module can also be used. Thus, for example, if h_p = 30 min., radial routes should have one-way travel time of approximately 12 min., allowing some 6 min. for both terminal times together. If V_o = 20 km/h (13 mph), the route length "module" would be L = 4 km (2.5 miles).

These elements determine that transit centers should be approximately 4 km apart. To provide staggered operation (with h = 30 min), the direct connector route should have N = 1; for simultaneous operation (with h = 15 min) N = 2 would be needed. Some centers may, however, be two modules, or approximately 8 km (5 miles) apart. For the same policy headway twice greater number of vehicles (N = 2 and 4, respectively) would be needed on the direct connector route. Or, with the same number of vehicles twice greater headway h = 60 and 30 min., respectively, would be obtained.

Each radial route can also be in multiples of 4 km, but for each multiple either N or h would increase by the same factor. Thus for an 8-km long radial route N = 2 would be required to have complete pulses (all routes meet) every 15 min. Or, with N = 1 this route would have h = 30 min. and thus participate in every other pulse.

In this example V_o = 20 km/h was assumed for all routes. If some corridors had V_o = 15 km/h or V_o = 25 km/h, the same basic headway, h_p = 30 min, would be translated into distance modules between centers of L = 3 km (1.9 mi) and L = 5 km (3.1 mi), respectively.

6.3 Final Network Planning

The analysis described in the previous section determines the required travel time and other operating elements in the network. An ideal fit of all these elements is, of course, rare. However, various adjustments can be used to make individual routes fit into the required distance or time/speed module (or its multiples). The primary methods of adjustment, summarized from section 4.3.3 are:

- The optional sections of routes, described in section 6.2.2, can be added or deleted depending upon whether cycle time (T) for that route must be lengthened or shortened;

- Terminal times can be adjusted to bring each route to the desired cycle time; these times can vary widely, from a minimum needed to recover delays (or, as required by union contract) to a maximum which causes maximum tolerable loss of time.

A final selection of transit centers from the previously defined set of feasible locations can now be made so that the network and its operating elements "fit" together.

With routes and centers determined, the final plan for physical and operational elements of the entire TTS network is made.

6.4 Summary of the Planning Procedure

The general procedure for planning and design of TTS, described above, is shown as a flow-chart diagram for one of the two cases. Figure 6.1 shows the TTS planning procedure for an area with conventional transit services. The planning procedure for a new TTS network differs from the procedure illustrated in Fig. 6.1 in two items. The first is that in the planning of a new TTS, the service area must be defined and many data must be estimated and projected since no transit service exists at present. And secondly, standards for the planned service must be developed to serve as guidelines in planning. Both of these activities would occur during the initial planning phase.

In general, planning for a new area is somewhat more extensive, but it does consist of the same general sequence of planning phases. These phases are as follows:

- Initial planning, consisting of the examination of the applicability of TTS to the area and its comparison with conventional service, definition of the service area and data collection.

- Analysis and preliminary planning, representing the most extensive phase, in which all network and operating elements are analyzed and related to each other.

- Final network planning encompasses selection of nodes and route alignments on the basis of preceding analysis.

- Final operations planning is determination of exact schedules after the final network has been designed.

Actual planning process is usually somewhat more complex than the diagram shows: the sequence of steps is neither as discrete nor as regular. In most cases the last three phases -- preliminary and final planning --

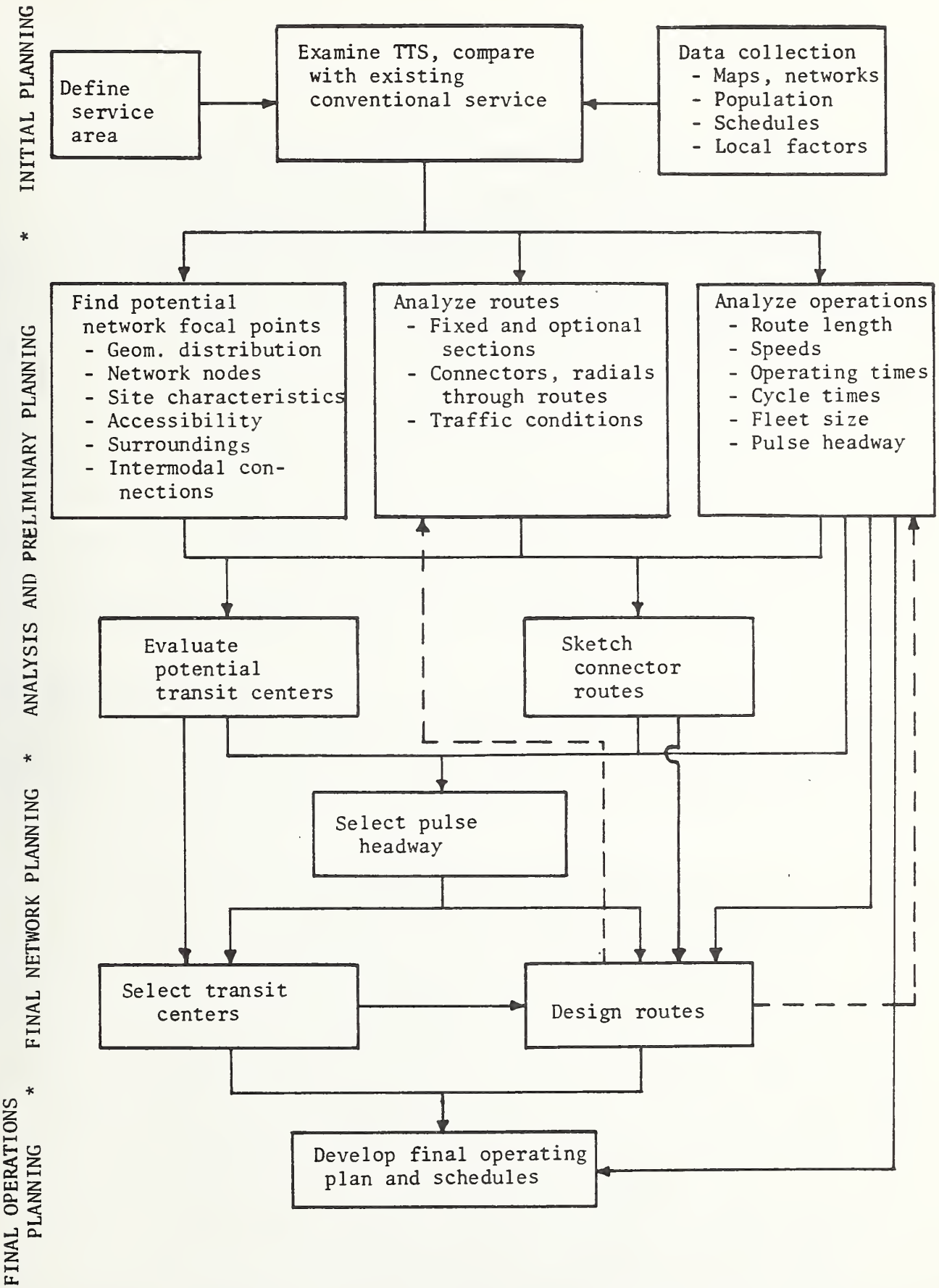


Figure 6.1 TTS planning procedure for an area with conventional transit services

are performed nearly simultaneously, as a complex iterative process. The planner must therefore be thoroughly familiar with the physical and operational characteristics of TTS (primarily the materials presented in sections 4 and 5 of this report), so that he can easily handle this analysis and select the best adjustments with imagination to derive an efficient final system plan.

Section 7

INFORMATION AND MARKETING

Passenger information and marketing activities, although often underemphasized by transit operators, are none the less essential management tools for the ongoing successful operation of any transit system. Although the introduction to the system of any new concept requires additional planning and careful implementation of its supporting information and marketing strategies, TTS by its very nature is particularly dependent on the effectiveness of these activities for its success. Without a well coordinated passenger information system that addresses the needs of the regular user, incidental user and out-of-towner alike, effectiveness of a TTS would be greatly decreased. Additionally, the introduction of a TTS affords the perfect opportunity for transit management to creatively market the new transit system (as distinguished from individual lines) that can dramatically increase the mobility of its users.

7.1 Information System

The use of the term "information system" implies that there are several components which complement each other in providing the public with information about the transit system. These components can be classified as:

- the type of information needed
- the locations where the information is disseminated
- the manner in which the information is disseminated.

In addition, the needs of different population groups must be carefully considered. The successful information system requires the appropriate combination of these components to provide each potential user group the information it needs in the most efficient way. Table 7.1 shows the different user groups listed in order of increasing information needs and the most common examples of each of the information system components listed above. In general, the information system should be designed to serve the needs of the least knowledgeable present or potential user group.

Since a TTS has a more extensive infrastructure than a traditional low-density bus network, its information system must be correspondingly more comprehensive. In addition to buses, stops, terminals and general community

Table 7.1 Components of an information system

User groups	Types of information	Location	Means of dissemination
Regular users on regular route Regular users on unfamiliar route Occasional users Visitors to the city	Network maps Route maps Schedules Fare information Transfer information	Stops Vehicles Terminals Banks, stores workplaces, etc. Other public places	Signs, markings and symbols Pamphlets Displays Telephone News media

information locations, the focal points of the TTS are obviously important locations for passenger information. Similarly, since transfers play a considerably more important role in a TTS than in other types of transit services, information about them must be more readily accessible than for uncoordinated services.

Information locations and methods of dissemination such as public places and the news media which tend to provide systemwide information will provide similar types of information in a TTS as a traditional network, albeit with a different emphasis. In a traditional network these outlets provide information about the overall network and schedules for one or all lines. For a TTS they must also specify the location, explain operational policies and schedules of all lines coming to the transfer points.

In any bus network, the stops should be clearly and uniformly marked and contain information such as the system logo, route designation (by street, route number or letter), transit agency name, and transit information telephone number. Major stops should also have information about the direction of vehicles ("Northbound", "Downtown" etc.), route map, timetable and stop designation. In a TTS, the information package just described should also emphasize which focal points the route passes through or terminates at, the connecting routes that can be transferred to and a schematic map showing all of the focal points. Figure 7.1 shows an example of a well equipped bus stop in a traditional network. Figure 7.2 shows what it should look like in a TTS.

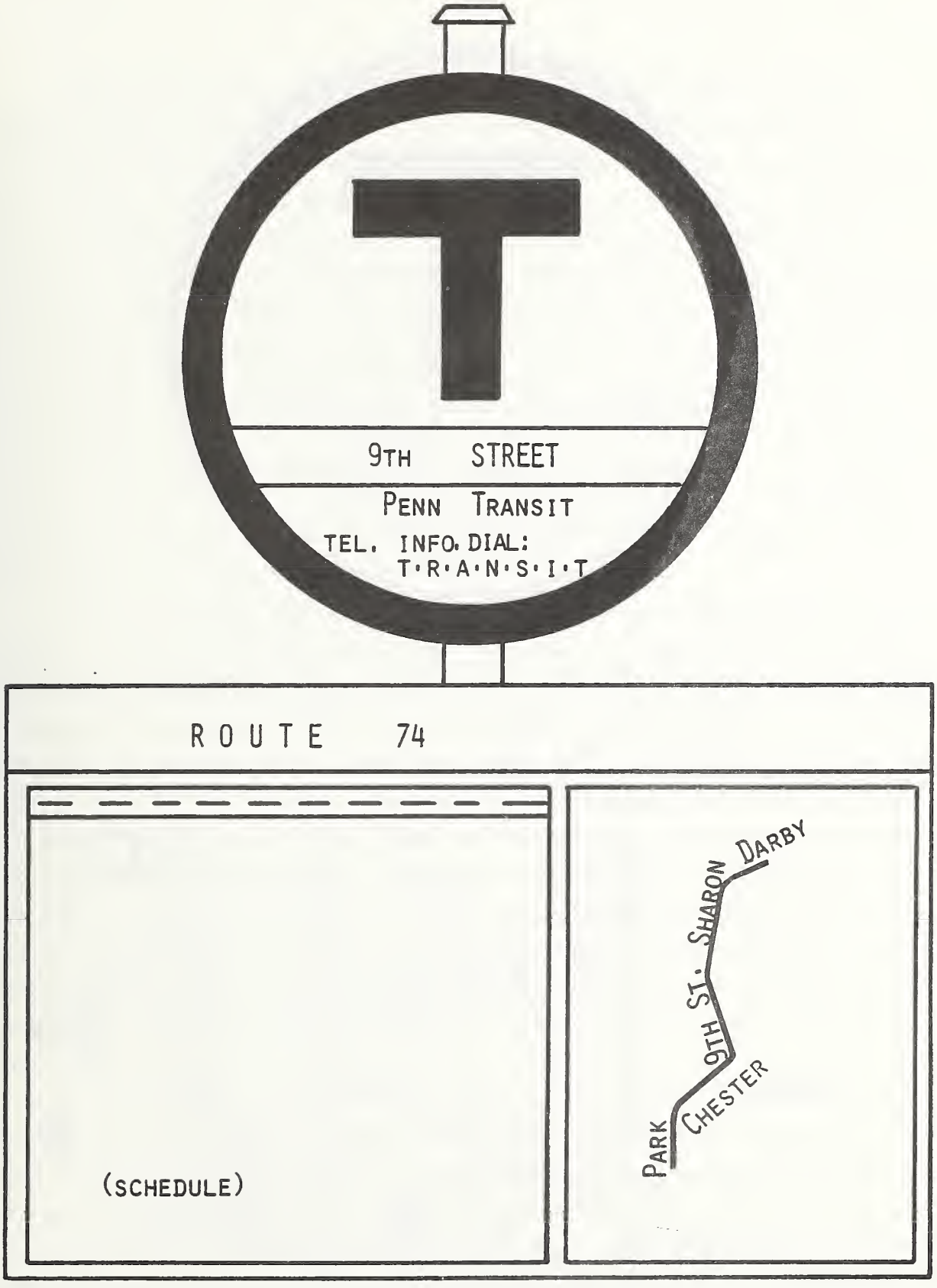


Figure 7.1 Transit stop sign and information for a conventional network

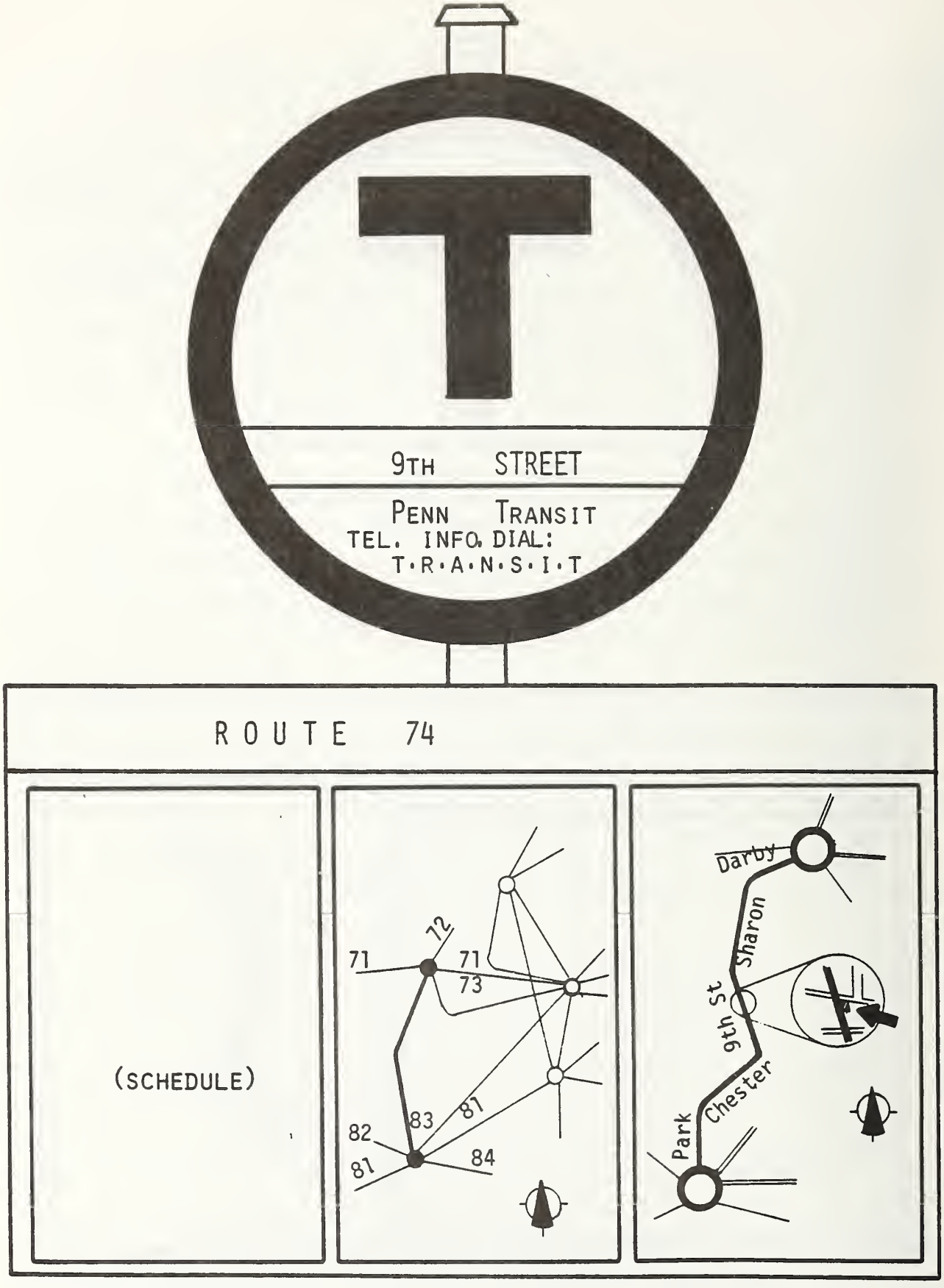


Figure 7.2 Transit stop sign and information for a TTS

Transit bus stops at railroad and intercity bus stations, or major shopping areas, are usually the busiest points of traditional networks. Therefore, the information provided at these stops needs to be significantly more extensive than that provided at other stops. In a TTS such facilities are also likely to be the network's focal points. Each one of these transit centers should be supplied with a complete set of transit information: schedules, stop locations, fare information, etc. for all lines of each mode. An information booth may also be necessary at selected, heavily used terminals such as airports and railroad stations in order to provide detailed specific information. System maps showing major points of interest and schedules for all modes should be posted and made available to the public. If the terminal is also a transit center, special emphasis should be placed on providing orientation for all transit routes serving that center. Figure 7.3 shows and example of a sign that can accomplish this purpose.

Transit vehicles, besides fulfilling their primary purpose of transporting people, are also important sources of passenger information. In any type of network the vehicle exterior should have the route number and destination prominently displayed on the front, back and right hand sides; the transit agency logo and name on all sides and the transit information telephone number on each side of the vehicle. The vehicle interior should display a route map with labeled stops, pocket maps and schedules of the route and those intersecting it, and any necessary regulatory signs such as "No Smoking". In a TTS the exterior destination sign should also include all focal points that the vehicle serves. Figure 7.4 shows an example of such a display. In the vehicle interior the names, locations and connecting routes of each transit center the vehicle passes through should be given special emphasis on the route map.

In implementing the information system, all items listed above cannot always be introduced into service immediately. When limited funds are a very real constraint, a list of priorities which reflects the most effective use of the available funds should be established.

To do this, a general rule may be applied: allocate funds on the basis of the ability to inform the maximum number of people about the system. A recommended grouping of priorities is shown in Table 7.2 which summarizes

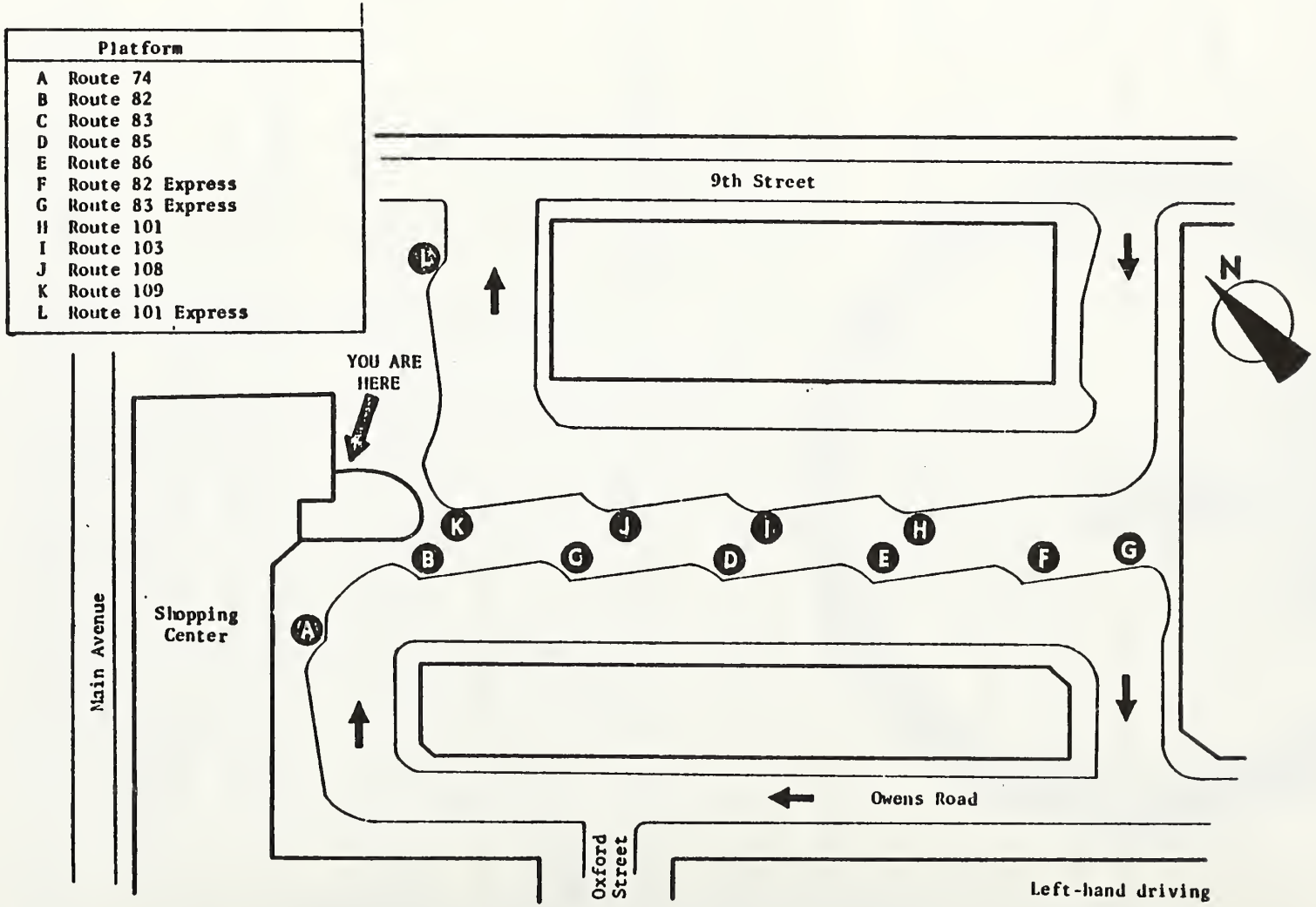
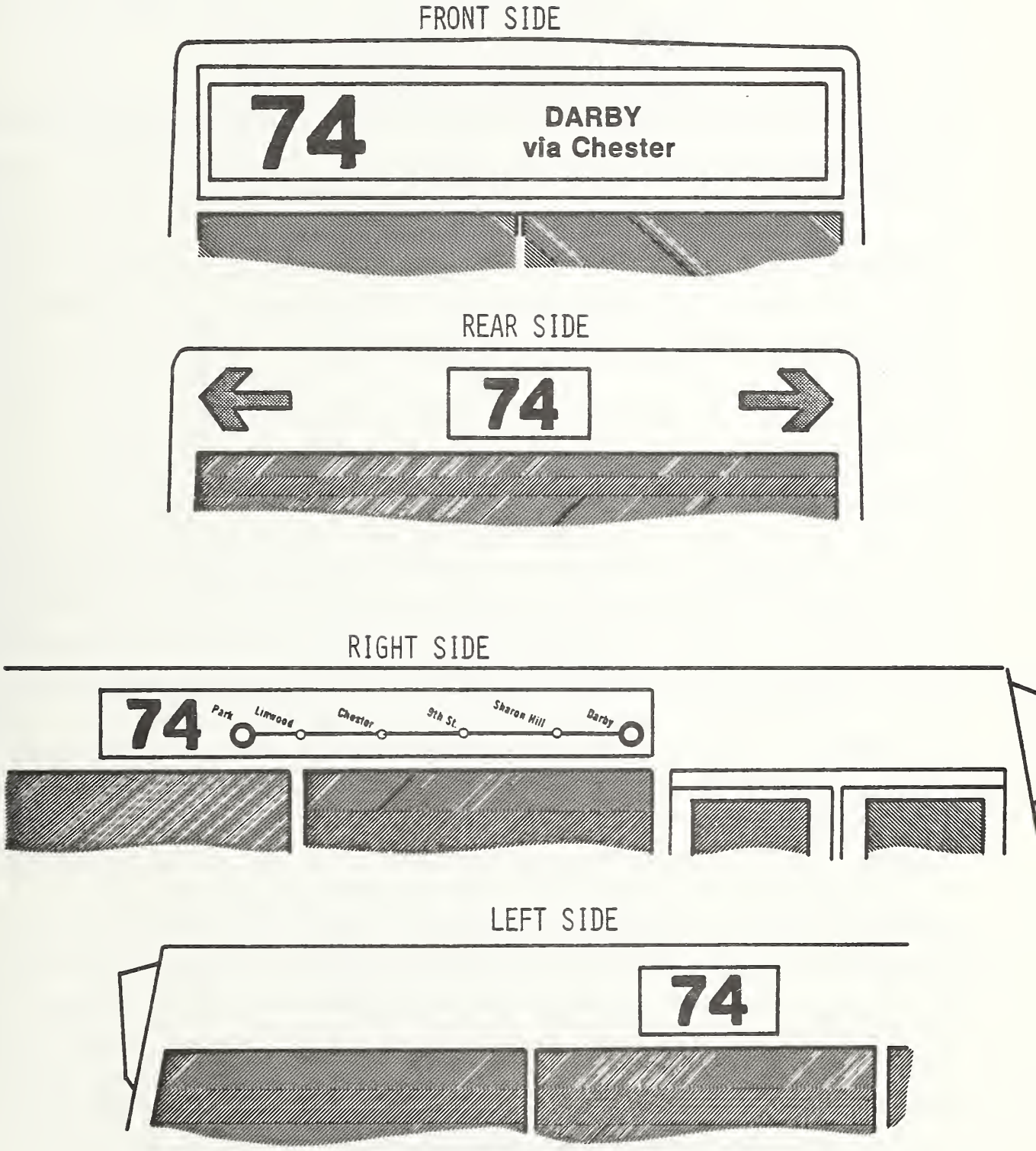


Figure 7.3 Terminal layout plan showing locations of stops for different routes (Based on Woden Interchange, Canberra, Australia)



7.4 Exterior vehicle signs in a TTS

Table 7.2 Summmary of transit information distribution system

Location	Primary group served				Type of information by priority		
	Regular user, regular route	Regular user, irregular route	Incidental and potential user	Visitor to city, new user	A	B	C
Transit stops/ terminals/ focal points:							
All stops	X	X	X	X	1,2	3	5
Major stops	X	X	X	X	1-3	4,5	
All mode terminal	X	X	X	X	1-6		
Mode transfer points (K+R,P+R)	X	X	X	X	1-5	6	
Transit center	X	X	X	X	1-5	6	
Transit vehicles:							
Exterior	X	X	X	X	1,2	5	
Interior		X	X	X	1-3,5	4	6
Public places:							
Hotels			X	X		2-5	6
Entertainment centers		X	X	X		2-5	6
Arenas, stadia		X	X	X	2,4	1,3,5	6
Schools, univer.	X	X	X	X	3-5	1,2	
Employment places	X	X	X			2-5	
Newsstands		X	X	X	4		6
Tourist bureau			X	X	2,4, 5,6		3

1. System name and symbol
2. Transit information telephone number
3. Route map and schedule
4. Transit network map
5. Fare information
6. Information on all transport services (other lines, long distance, taxi)

the elements of the information system described so far: the locations of distribution, the types of users, the type of information, and the means of distribution.

7.2 Marketing

To attract its potential riders, every transit agency should have a well organized marketing program. For a TTS,the structure of the marketing program does not have to be different from that used to promote any other type of transit service, but the content should differ somewhat. Since the purpose of a TTS is to provide a better integrated transit service than a traditional network in low density areas allows, the marketing effort should reflect this feature and emphasize particularly the network or system characteristics of the TTS service.

Any marketing program can be broken into two components:

- Marketing strategy; and
- Marketing activities.

7.2.1 Marketing Strategy. The marketing strategy is a consistent plan of coordinated marketing activities that has defined objectives with regard to passenger attraction and provision of service. Three types of marketing strategies can be used, individually or in combination:

Undifferentiated marketing promotes the use of the transit system in general to the entire public.

Differentiated marketing addresses different population segments with different approaches based on their specific needs.

Concentrated marketing promotes the use of a single component or feature of the transit service; or it is aimed to attract a selected population segment.

In general, undifferentiated marketing is the simplest and least expensive strategy of the three to implement. However, it also has the most dispersed impact on human behavior which is difficult to measure. The choice of marketing strategy(ies) will depend on the role of transit in the area, available resources, community characteristics, and the type of transit service. Reliance on undifferentiated marketing would only be appropriate if there was limited funding available for marketing, and the community is economically and socially rather homogeneous. Otherwise, differentiated or concentrated marketing is called for to supplement the undifferentiated marketing. In a TTS,the special importance of the transit

centers in the transit network would probably indicate the use of some form of differentiated or concentrated marketing with regard to their purpose and method of operation.

7.2.2 Marketing Activities. Marketing consists of many different activities which can be classified in the following major categories.

a. Market Research, in which information is collected about the characteristics of the community, its population, transportation patterns and demand features. This would include such information as physical features of the city, demographic characteristics, sociological factors, origin-destination data, auto ownership data, travel peaking characteristics, etc.

This activity is basic to any marketing program regardless of network type.

b. Market Segmentation is the procedure which divides the users and potential users of transit into classes or groups, based on social, economic, geographic or other characteristics which differentiate between the transit needs of individuals. It is after market segmentation that the differentiated marketing strategy or the concentrated marketing strategy is applied.

The degree of market segmentation attainable depends on the kind and amount of data gathered during the market research phase.

Table 7.3 shows selected characteristics convenient for market segmentation. A market group may be formed on the basis of one, or a combination of any number of the factors listed. However, in deciding how to segment the market, the following criteria should be adhered to:

- Each segment should have a sufficient number of people to justify the cost of advertising to that group individually.

- Each segment should be distinct in its needs for and attitudes toward transit.

Although these characteristics vary among localities, it is possible that the introduction of a TTS may so greatly benefit one particular user group as to dictate market segmentation along those lines. For example, if a transit center is combined with an important shopping center the current and potential shoppers may well be a relevant and easily identifiable market segment.

Table 7.3 - Characteristics commonly used in market segmentation

Type of characteristic			
Social/economic	Trip	Time of trip	Geographic
Age Education Sex Family size Occupation Income Auto ownership Driver/non-driver	Work Shopping Recreational Medical Educational	Peak Off-peak Weekday Weekend	Trip length Trip ends CBD-internal CBD-suburb Suburb-CBD

c. Service Adjustments. On the basis of data collected during market research and market segmentation, it may become apparent that certain modifications to service are required. These include route modifications such as rerouting, elimination or addition of route segments, elimination of duplicate routes and introduction of new ones; fare adjustments, such as a change in fare structure and the introduction of special fares; schedule changes (typical for TTS introduction); and operational modifications such as express, skip-stop and shopper specials that are possible in a traditional network; and the location, number, type and operation of the transit center. All these modifications can be components of a comprehensive marketing activity.

d. Information Distribution is another essential component of a coordinated marketing program. See Section 7.1 for the details about the information system specifically designed for a TTS.

e. Advertising, the activity most commonly associated with marketing, has three related purposes:

- To draw public attention to the transit service;
- To inform the public of the qualities or advantages of the transit service; and
- To create a positive image for transit in the eyes of the public.

Public attention can be drawn to the transit service in a number of ways, some of which were already discussed in the preceding sections. Among these ways are distribution of printed media (brochures, pamphlets, newspaper advertisements, posters, billboards, yellow page advertising, direct mailing, etc.), radio and television commercials, the design of stations, stop designations and the selection of system color theme (for signing, vehicles, schedules, etc.).

In informing the public of the qualities and advantages of the transit service, practical appeals should be emphasized, such as:

- Money savings (e.g. the annual savings of an actual transit rider over what otherwise would be spent on an automobile).
- Time savings (where applicable).
- Comfort and convenience (e.g. ability to read on transit, avoidance of aggravation in traffic jams and parking problems, etc.).
- Increased safety and reliability (e.g. comparing accident rates, percent of on-time arrivals by transit).

At times, practical appeals are not sufficient to overcome the negative image that transit has acquired in many cities. Therefore, it is desirable to convince the public that it is not only "socially acceptable" but even "fashionable" to ride transit. This can be accomplished if a certain status image can be developed for the transit service. Such an image is developed in advertising:

- By appealing to the public spirit: using transit saves fuel, helps reduce air pollution, etc.
- By implying that transit users are "smarter" than auto drivers.
- By using celebrities and prominent community leaders to endorse transit, where in fact they do use it.

In a TTS, special emphasis can be placed on the convenience of now being able to travel between many pairs of points that previously required inconvenient and/or synchronized transfers.

f. Public Relations encompass all the marketing activities whose purpose is to provide a positive, progressive image of the transit agency and service. In addition to a reasonably good level of service offered to the public, which is, of course, essential for any successful public relations campaign, contacts with the general public, press, and other governmental agencies form the basis of the public relations effort.

The general public's image of the system can be enhanced by such civic activities as participation in charity drives, assisting in job training programs, assisting in local planning boards and participating in special events such as holiday parades, sports events, etc. Attitudes of the riding public are greatly influenced by such service features as clean and well maintained vehicles, bus shelters in good repair, helpful and courteous employees, an effective complaint department, a lost-and-found and information

services, and apologies about breakdowns, delays in service, etc. In a TTS this last item is particularly important. If a bus is being held at a transit center for the arrival of another bus, the passengers should be informed of the reason for and the extent of the delay. If the buses are in radio contact with each other or a dispatcher, then the passengers on board the incoming bus should also be made aware that the connecting bus is being held for them.

Regardless of the type of network, carefully planned and maintained relations with the press and various governmental agencies are also important public relations elements. Favorable news stories about the transit agency in the press not only bolster its image, but also reduce the amount of money required for advertising. Open communication channels with other governmental agencies reduce the misunderstandings that can arise concerning funding, planning, regulation, etc. and thus allow the transit agency to more profitably direct its energies toward managing the transit system.

7.2.3 Review of Marketing for a TTS. The above described marketing techniques apply to transit services in general. However, in each specific case marketing activities should be adjusted further to the specific service and user characteristics. In the case of TTS, marketing should include the specific aspects of this operation.

Introduction of a TTS significantly changes the service offered by a transit operator, particularly in low density areas. While formerly uncoordinated services with long headways had caused a great inconvenience with all transfers, TTS insures easy and convenient transferring among most or all routes. Thus, a set of independent services has been replaced by an integrated network service. This fact should be marketed intensively, to inform the public about the new travel possibilities.

Market for a TTS can generally be segmented into at least four groups of potential users. Each one of them may require somewhat different marketing emphasis, techniques and tools.

a. Present transit users, who are likely to continue to use transit services, may be able to make additional trips due to the new network service. They should be informed about the new possibilities and encouraged to use them. A particular goal should be to increase non-work, off-peak travel, which TTS can serve much better than uncoordinated services.

Since these riders are already in the system, they are the easiest group to reach in any marketing campaign. Distribution of special brochures and schedules in vehicles or at terminals represent the simplest and least expensive method for this marketing effort.

b. Served area residents who are not transit users represent usually a large group from which some new transit users can be attracted by the new TTS service. Many trips previously made by auto out of necessity could now be made by transit.

The marketing campaign for this group should be designed to achieve the following:

- Inform the non-users about the new type of service available;
- Inform these people how they can obtain information about specific trips and how to use the system;
- Eliminate the often existing image of transit as an "inferior" service and create a positive image due to the new type of service.

Reaching these potential users is much more difficult and expensive than reaching current users. However, in addition to methods described in section 7.2, some factors related to a TTS operation can aid in targeting these potential customers. First, if a TTS is limited to specific suburban areas rather than the entire metropolitan area, local suburban newspapers, radio stations, community centers, etc. should be used for concentrated marketing. Second, billboards can be carefully placed along highways which service auto drivers who may switch to transit.

c. Residents in the vicinity of transit centers, which are a special subgroup of the group described under b, should be given separate attention. In most cases transit services from transit centers is greatly improved with TTS over the preceding ones, so that transit penetration into the travel habits of these residents should be particularly significant. Marketing for this group is not as difficult and expensive as it is for more dispersed groups. First, transit brochures and schedules should be distributed to the population within a 10-min. walking distance from the centers at their homes; and second, if transit centers have any stores, a bank, post office, community centers, etc., attempts should be made to integrate TTS advertising with that which these outfits are doing for themselves. Ride-and-shop (reimbursement of transit fares to store customers) is often a powerful scheme to attract shoppers, and it can be combined with TTS marketing to increase customers in the area through newly improved accessibility.

d. Non-area residents, or newcomers and visitors to the area served by a TTS, should be attracted to transit by the methods described earlier in this section, but with a special emphasis on the convenient integrated network services. The concept of TTS, including the transit centers, pulsing and easy transfers, must be explained to the newcomers. Methods of marketing for this ridership group have been explained, for example, in Refs. [7 and 9].

8. AN EXAMPLE TTS APPLICATION: RED ARROW DIVISION OF SEPTA (PHILADELPHIA)

In order to apply computational elements and operational concepts and to test the TTS planning procedures presented in the preceding sections, a hypothetical plan for TTS operation in southwestern suburbs of the Philadelphia metropolitan area was developed. This area was selected as appropriate for a TTS, based on the form, density and other criteria presented in the sections 4 and 6. Moreover, transit services in this area are partially separated from the transit system in Philadelphia: the once independent Red Arrow system is still operated as a semi-independent Red Arrow Division (RAD) of the Southeastern Pennsylvania Transportation Authority (SEPTA). Although this plan has not been implemented, the planning exercise, presented in this section, offered interesting procedural experiences and results.

8.1 The Existing Services

The RAD provides services by three light rail and more than 20 bus routes. Most of the routes (more than 60%) radiate from a major rapid transit terminal - the 69th Street Station, as Fig. 8.1 shows. Darby, Chester and Ardmore stations also represent major terminals, each being served by six or more rail and bus routes. Darby has two heavily used streetcar lines connecting it with center city Philadelphia, while both Ardmore and Chester have major regional rail stations. The busiest RAD routes are the light rail rapid transit line from 69th Street to Norristown and light rail transit lines from 69th Street to Media and Sharon Hill. The Norristown terminal is presently the only TTS transit center in the entire metropolitan area.

The most common service frequency in RAD network is 3-4 departures per hour. Schedules for most lines are not mutually coordinated. Terminal times vary.

Most routes follow major arterials, which are also corridors of most intensive commerical development. Many route sections are, however, primarily performing collection/distribution functions in residential areas.

This and much more detailed information about the existing RAD services and about the area were collected as the initial phase of TTS planning.

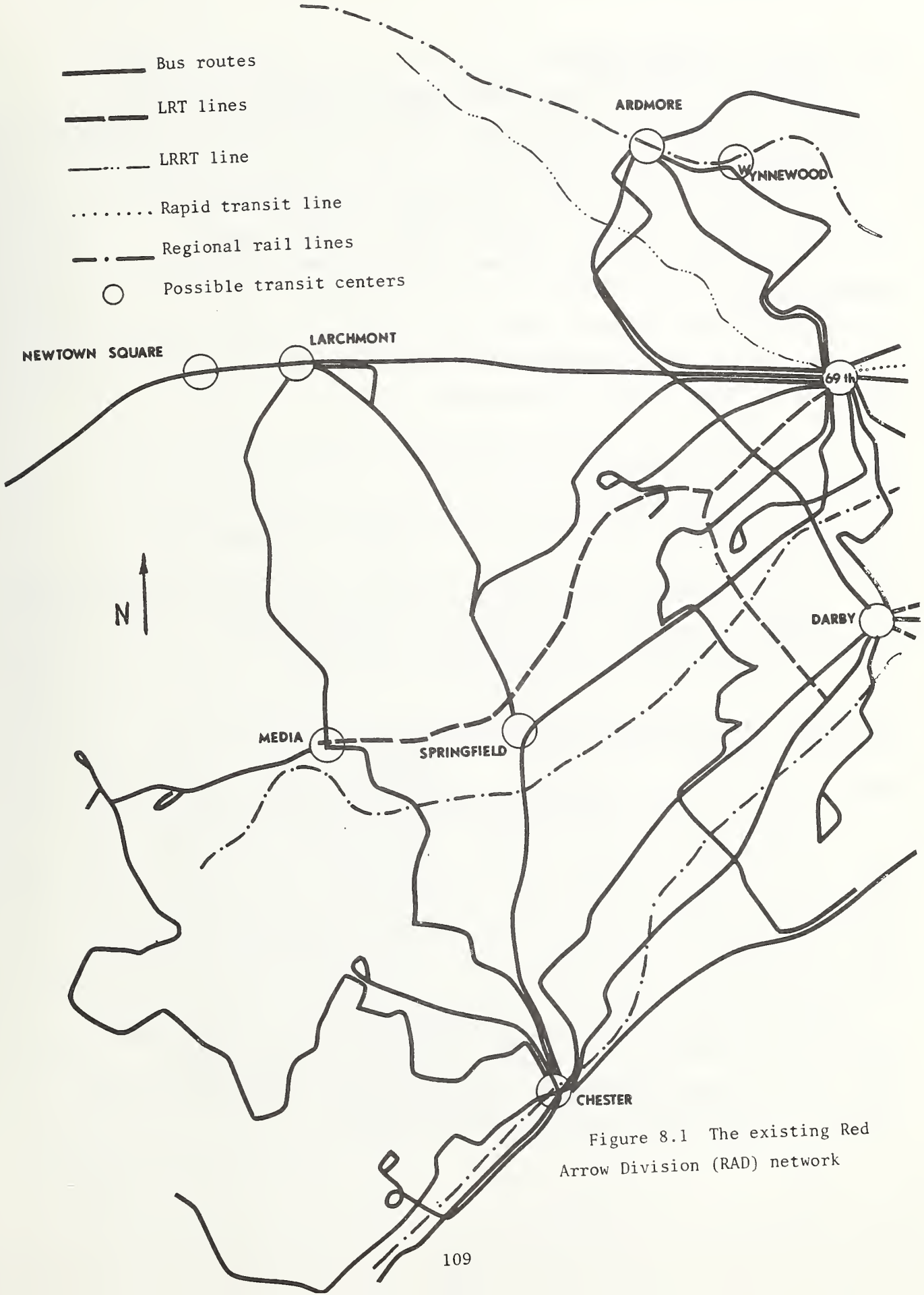


Figure 8.1 The existing Red Arrow Division (RAD) network

8.2 Potential Transit Centers

RAD service area and network were carefully reviewed to determine potential locations for transit centers. The following types of locations were examined:

- Shopping centers: Ardmore, Springfield Mall, Wynnewood;
- Major activity centers: Ardmore, Chester, Darby, Media;
- Transit route crossings: Ardmore, Chester, Darby, Larchmont, Newtown Square;
- Major transit terminals: 69th Street Station, Ardmore, Chester.

Each one of these locations was examined with respect to all characteristics required of transit centers.

8.3 Route Analysis

The existing routes have been classified into three categories by their general orientation:

- Direct, connecting focal points by alignments with shortest travel times;
- Local, connecting focal points and serving local areas along the way; and
- Radial, going from a focal point into suburban areas.

The classification of routes is given in Table 8.1.

Table 8.1 Classification of the existing SEPTA/RAD routes by type

Direct	Local	Radial
74, 80, 83, 101, 104A, 106, 109, 113	46, 72, 76, 77, 103, 105, 110	Market-Frankford, E, D, 11, 13, 37, 44, 70, 100, 102, 107, 108, 111, 112

Routes Market-Frankford, E, D, 11, 13, 37, 44 and 46 are not part of the RAD, but of SEPTA's City Division. They were included because of their direct interaction with many RAD routes.

With a preliminary set of transit center locations, all routes were classified as terminal or through for each location. Their numbers and possible transfer permutations were computed for each potential center location. These numbers are presented in Table 8.2.

Table 8.2 Number of routes by type and possible numbers of transfer permutations

Potential center location	Terminal routes	Through routes	Transfer permutations
69th St. Station	18	-	306
Ardmore	5	-	20
Chester	4	3	84
Darby	6	1	54
Larchmont	2	2	26
Media	2	1	10
Newtown Square	-	2	8
Springfield Mall	1	2	16
Wynnewood	-	2	8

The table clearly shows the heavy dominance of the 69th Street Station, and the presence of six other substantial transfer points (Newtown Square and Wynnewood are only intersections of two through routes).

In further analysis other factors were taken into account. For example, Springfield Mall does not have all three routes physically close to each other. Media, although weak as a transfer point, is a major activity center which makes it a more powerful generator of passenger trips than the single-purpose (shopping center) development at Springfield Mall. Other factors considered in the center and route analysis were traffic conditions along corridors and at centers, required route deviations and land availability at center locations.

8.4 Analysis of Operations and Development of the Final Plan

Operating elements, such as L, h, T_o, t_t, T and N, for each route were obtained from SEPTA. Extensive analyses of routes and their possible revisions and rescheduling were performed. Area coverage, operations of each route and of each potential center were examined and the following major conclusions were reached.

Springfield Mall and Wynnewood shopping centers were discarded as transit centers. Media was found to be superior to Springfield as an activity center and because of superior service by the Media light rail line; use of both is impractical because of their physical closeness. Ardmore proved to be a stronger transit trip generator and required less route realignments than Wynnewood.

For Newtown Square and Larchmont, the primary consideration was that two routes were already terminating at Larchmont and that Newtown Square had two through routes with similar alignments.

The TTS area was then delineated on the basis of selected center locations and direct routes, as shown in Fig. 8.2. After this, planning and scheduling of individual routes were undertaken.

The formed network of direct connector routes among the selected transit centers, shown in Fig. 8.3, served as a skeleton for the planning of other local and radial routes. An attempt was made to provide relatively short headways on direct routes so that travel between focal points of the network is facilitated. Then the selection of the pulse headway, h_p, was made.

Analysis of headways and cycle times showed that headways of 30 min. predominated and appear logical as the basis for the TTS in this area. However, an interesting deviation from the uniform h_p for the entire area was made. The network is strongly connected with city transit routes at its two eastern centers, the 69th Street Station and Darby. 69th Street Station, with schedule as shown in Fig. 8.4, is served by rapid transit line with short headways (<10 min) throughout the day. Most transfers are from RAD (light rail and bus) lines to the rapid transit line (and v.v.), so that pulsing of RAD lines is not advisable. It would cause uneven loadings on rapid transit trains and benefit very few riders who transfer among RAD routes. Darby is served by streetcar lines operating with 10 min. headways, making 10- and 20 - min headways optimal for RAD buses. The outlying portions of the RAD network would be getter served by 15-, 30- and 60 min headways.

To satisfy these different requirements for the "inner" and "outer" sectors of the network, different values were adopted for h_p. Darby was synchronized on the basis of h_p = 10 min. (and its multiples), Chester on h_p = 15 min and its multiples. The two connecting routes between these two centers, 74 and 76, operate with the joint headway for both centers, 30 min. Ardmore was synchronized for h_p = 30 min., with one route (44) having 15-, and another (83) 60-min headways.

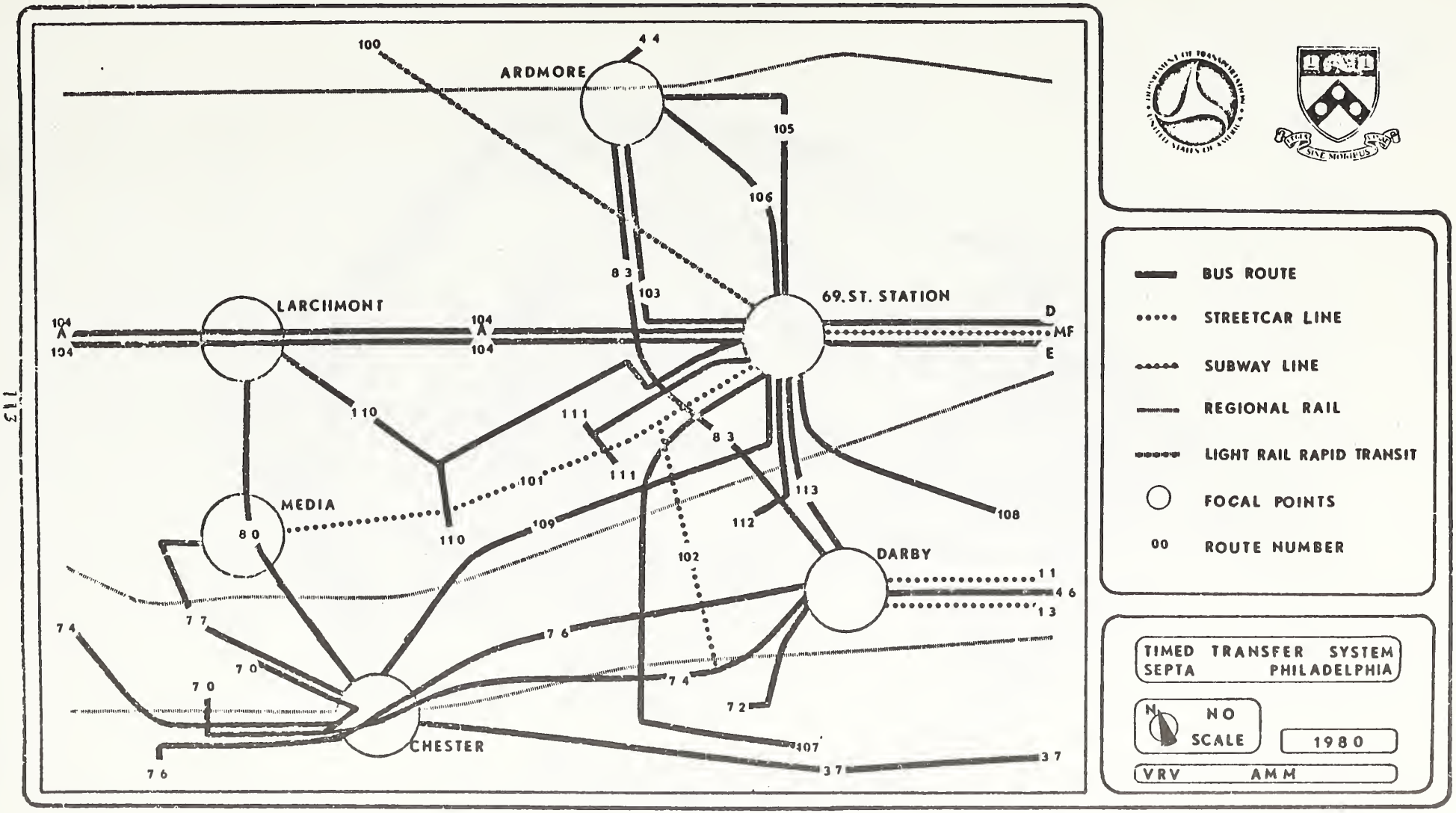


Figure 8.2 Schematic of RAD network with selected transit centers

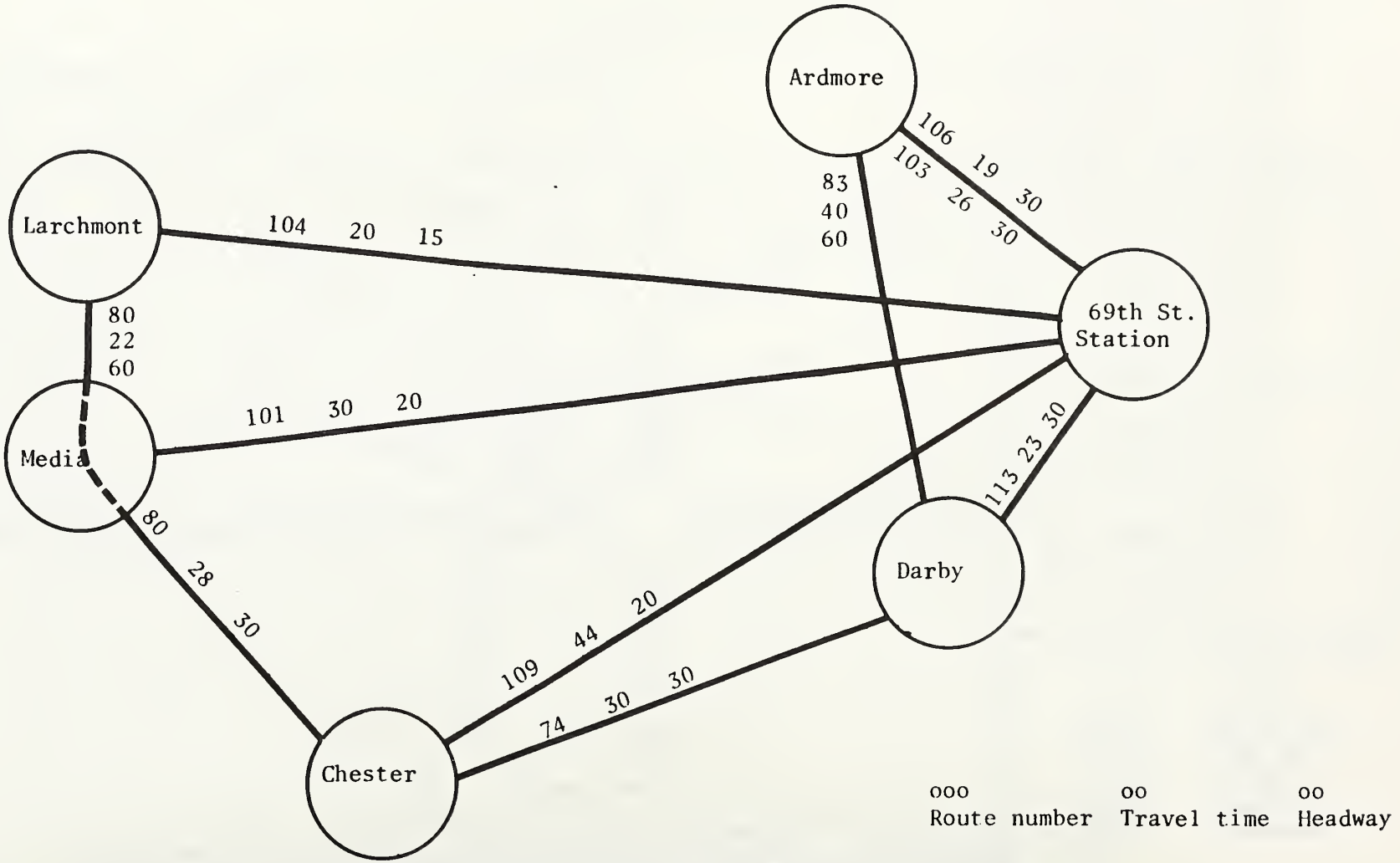


Figure 8.3 Transit centers with direct connector routes

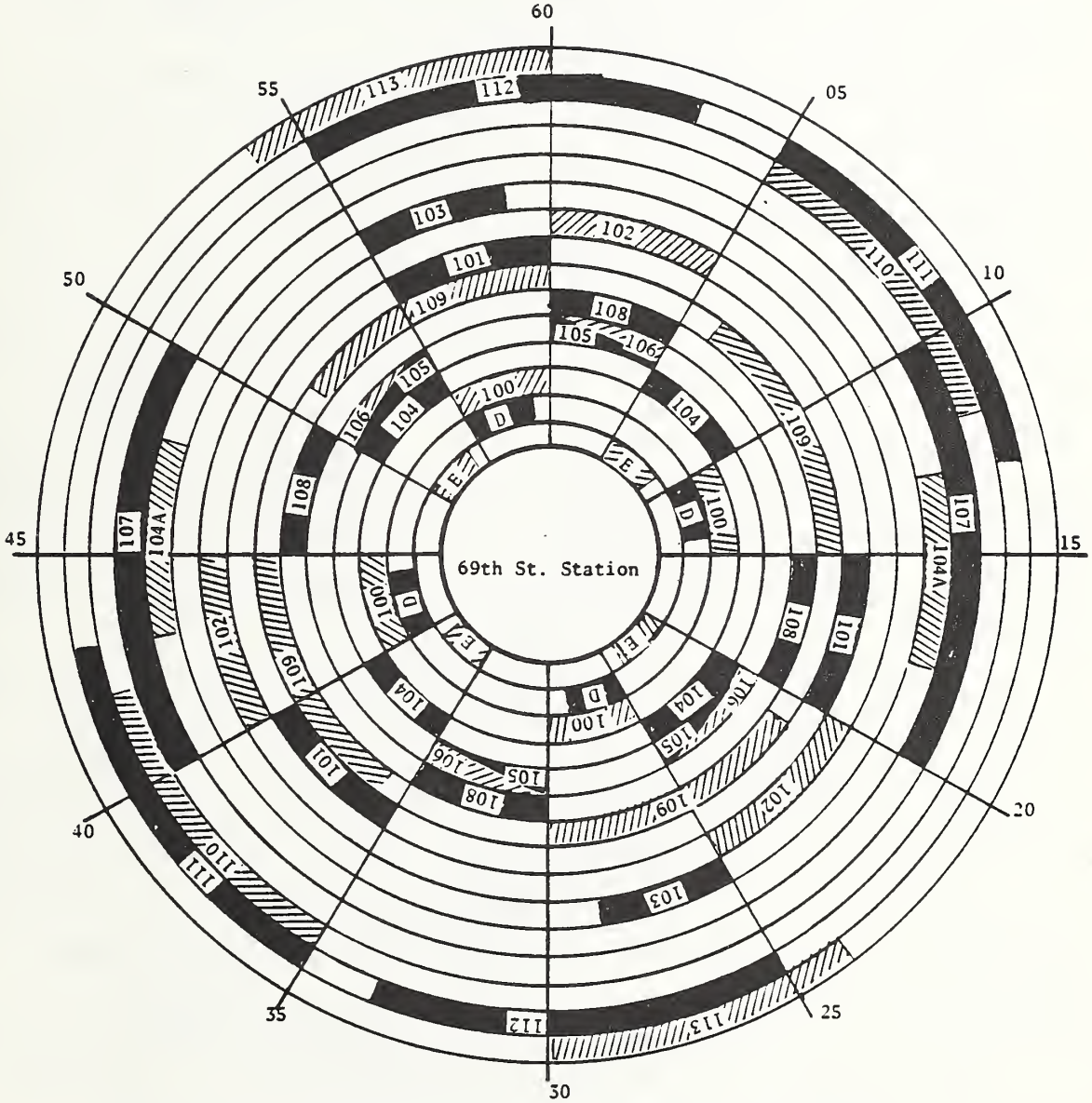


Figure 8.4 Present schedules at 69th Street Station

Several route adjustments were needed to achieve this scheduling. For example, route 77 was found to be too long to fit appropriately into the TTS: it had one-way operating time of 65 min. the plan is therefore to divide the route into two sections, one from Media, the other from Chester. Passengers traveling from Chester to the upper portion of route 77 (see Fig. 8.1) would go to Media by route 80 and transfer there to route 77A, and v.v.

Routes 46 and 72 were linked together to make one route that could fit to a headway of 30 min, eliminating the long terminal times (15 min or more). Route 107 was shortened by the elimination of the lightly traveled section between MacDade Mall and Westinghouse Village.

8.5 Partially and Fully Synchronized Schedules

In the reorganization of conventional into TTS service, an important question is whether the vehicle fleet (and therefore costs) will be increased. Fully synchronized TTS usually requires a larger fleet; but partial synchronization can often be achieved with an unchanged number of vehicles.

To examine separately the impact of reorganizing the existing service into TTS and then the impact of full synchronization on level and costs of service (or, more specifically, types of schedules and fleet requirements), two schedules have been made:

- Partially synchronized service, or TTS service with the same number of vehicles operating on each route as now; and
- Fully synchronized service; this represents full schedule coordination at the centers, often requiring increased numbers of vehicles.

The developed schedules for the major transit centers are presented in a series of figures. Three schedules for the Darby center, existing, partially and fully synchronized, are shown in Figs. 8.5, 8.6 and 8.7. The following four figures, 8.8 - 8.11, show in sequence: Chester partially and fully synchronized and Ardmore partially and fully synchronized.

Basic operationg elements for all lines for partially and fully synchronized schedules were computed. As mentioned, partially synchronized has the same fleet size as the existing conventional services. Interestingly, in this particular case full synchronization would require an increase in the number of vehicles in operation of only 7.5%. This is

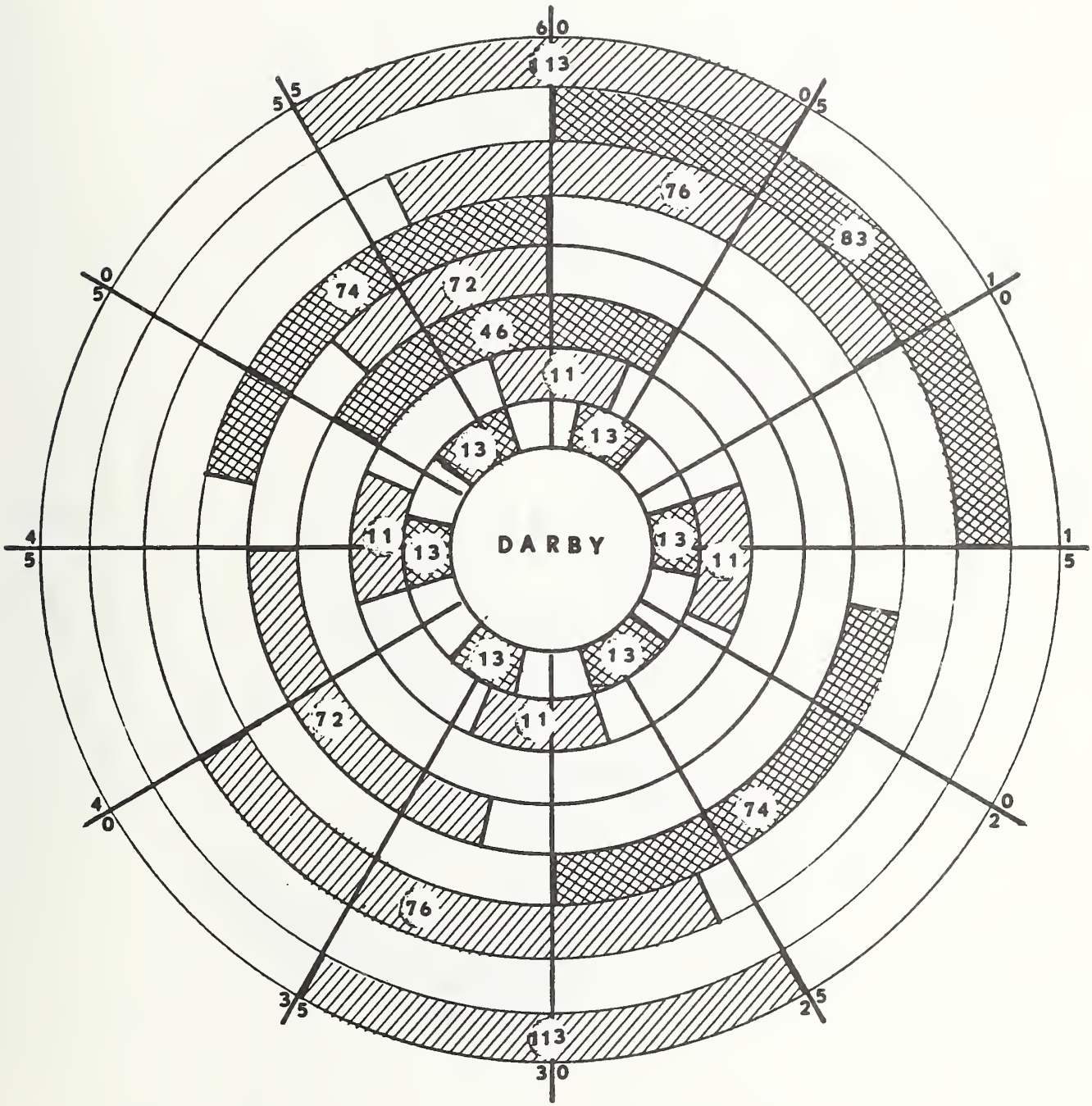


Figure 8.5 Darby station: present operation

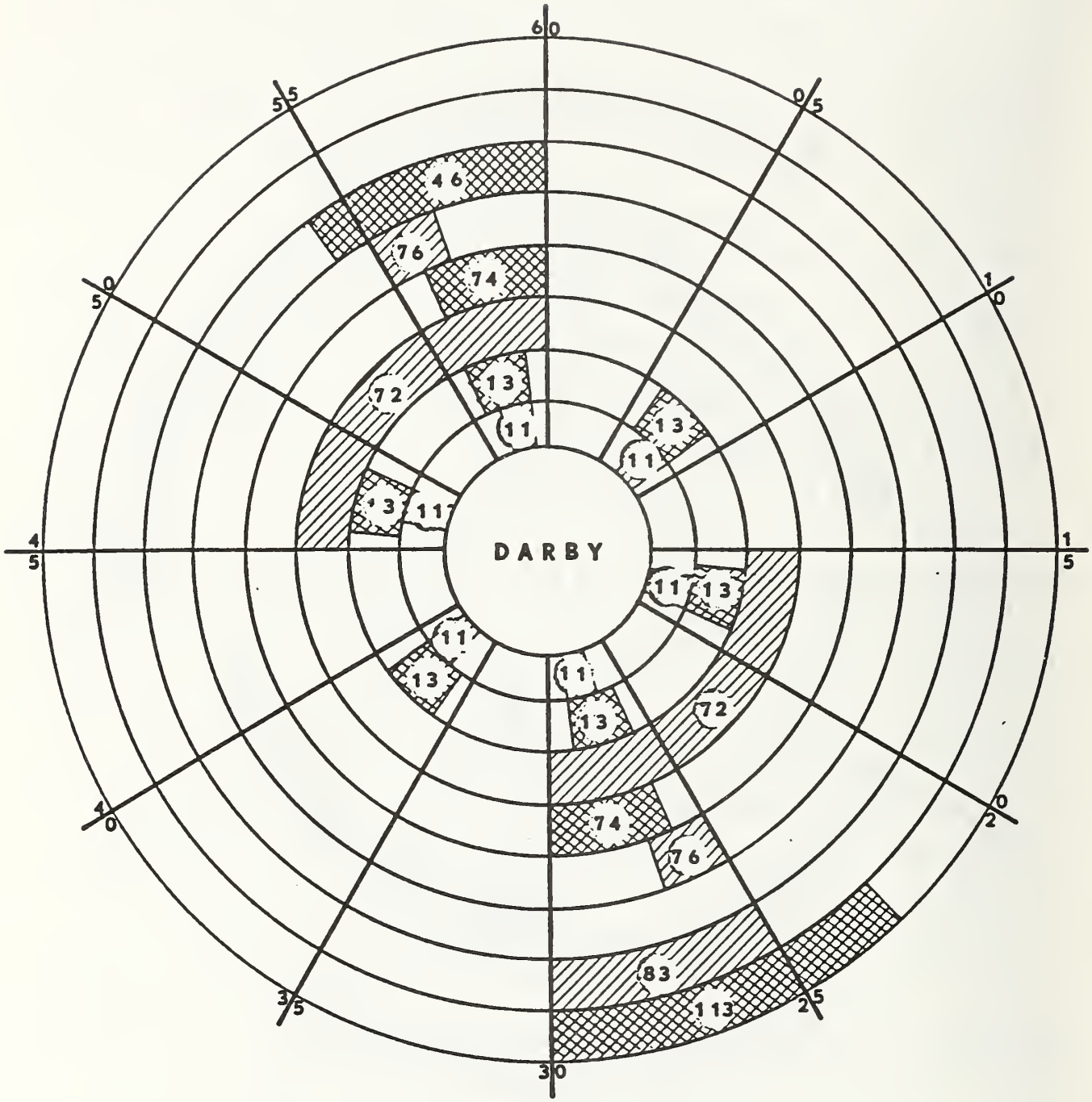


Figure 8.6 Darby transit center with partially synchronized schedules

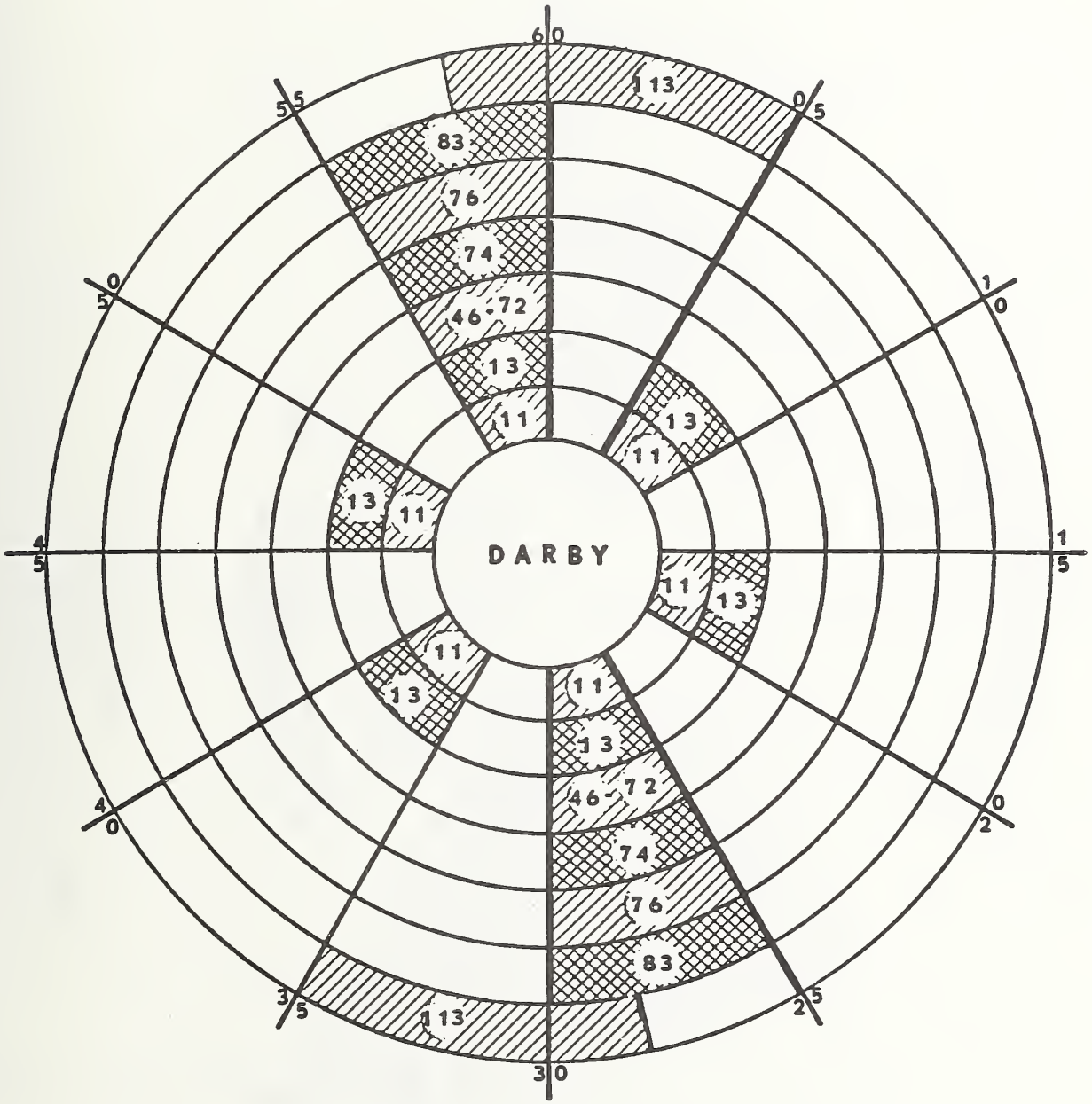


Figure 8.7 Darby transit center with fully synchronized schedules

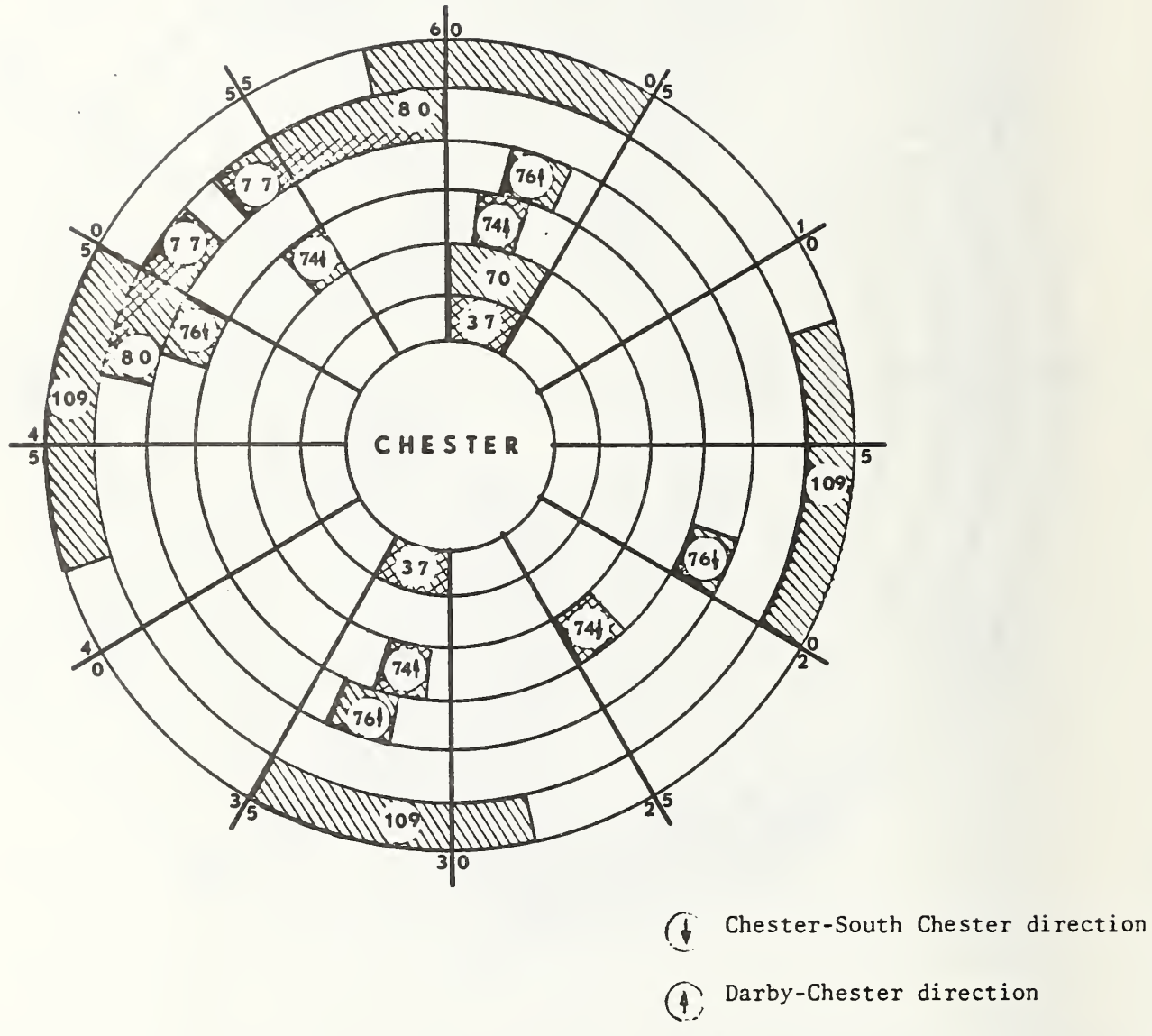


Figure 8.8 Chester transit center with partially synchronized schedules

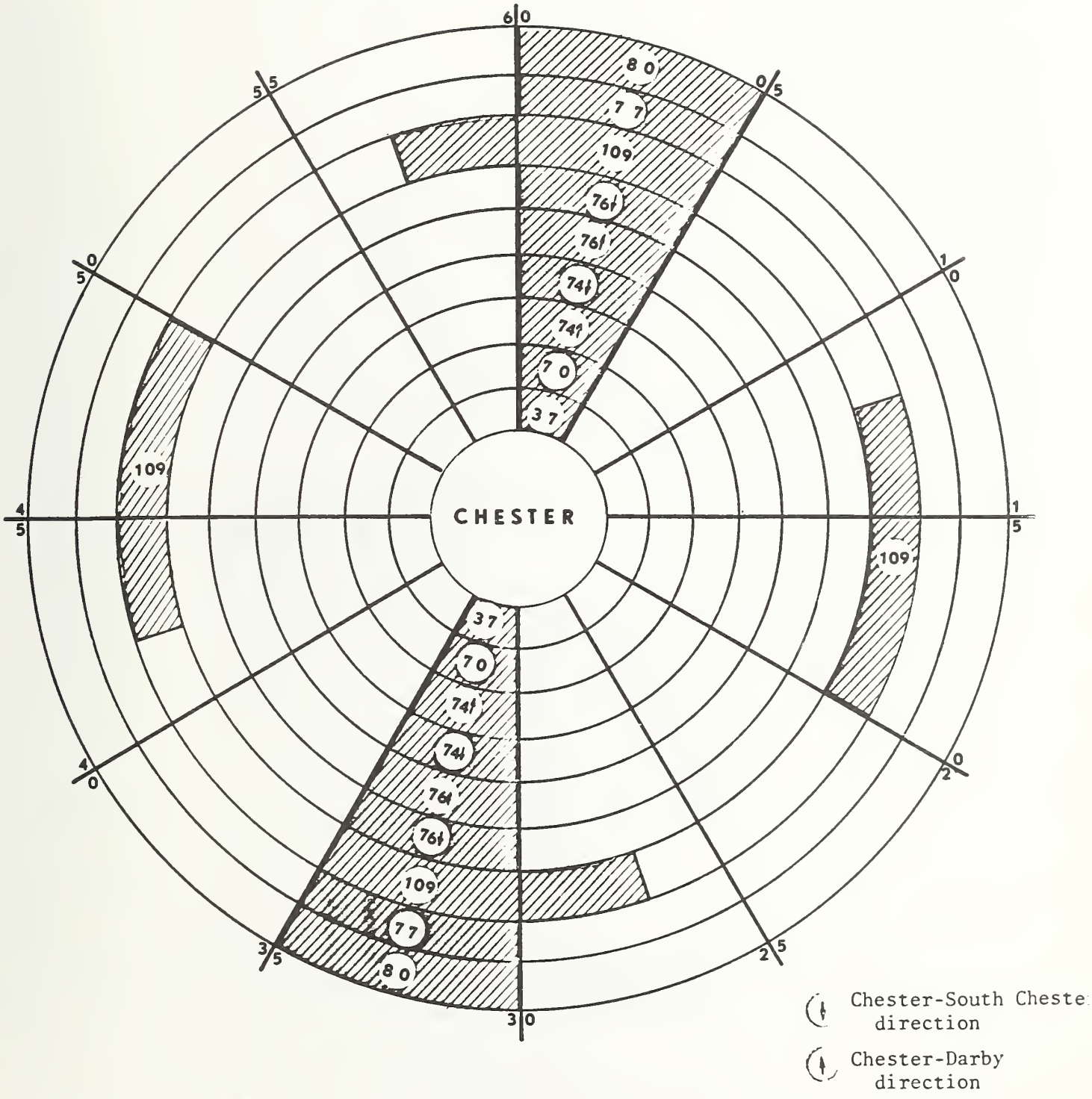


Figure 8.9 Chester transit center with fully synchronized schedules

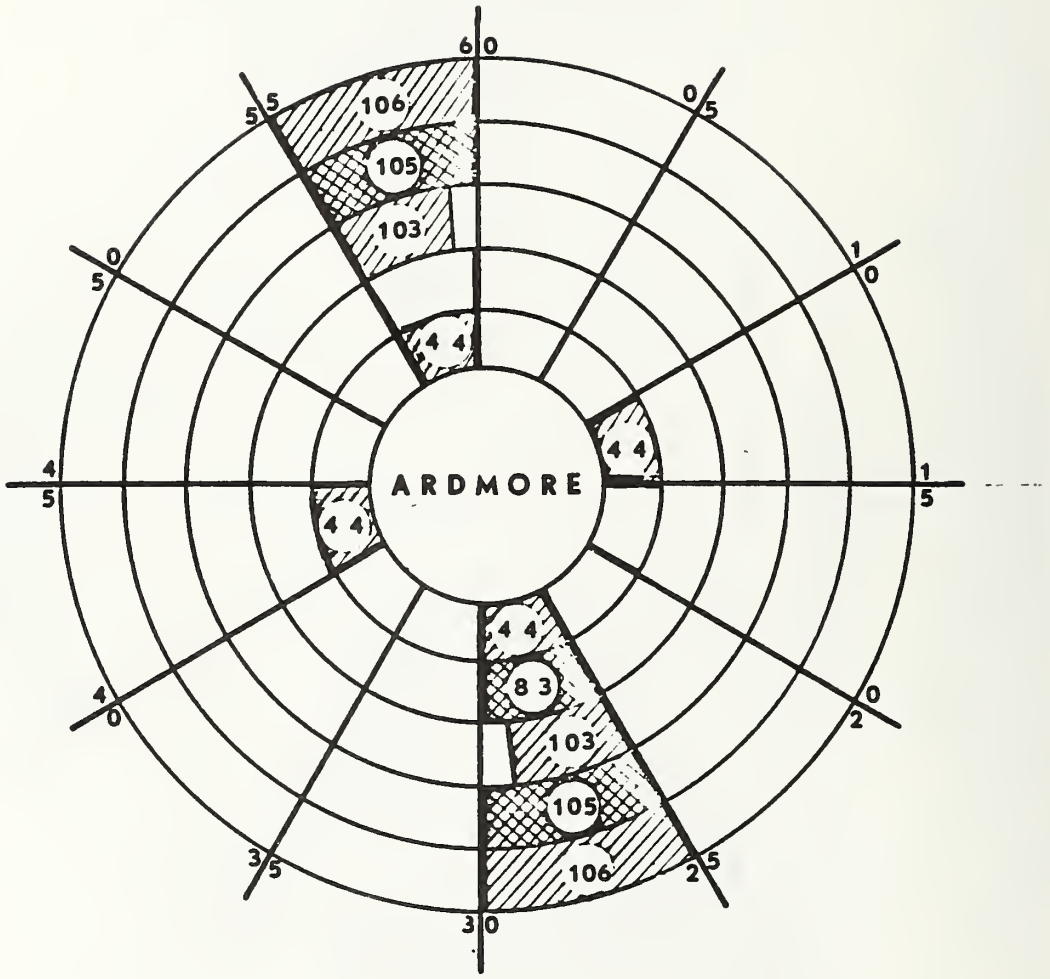


Figure 8.10 Ardmore transit center with partially synchronized schedules

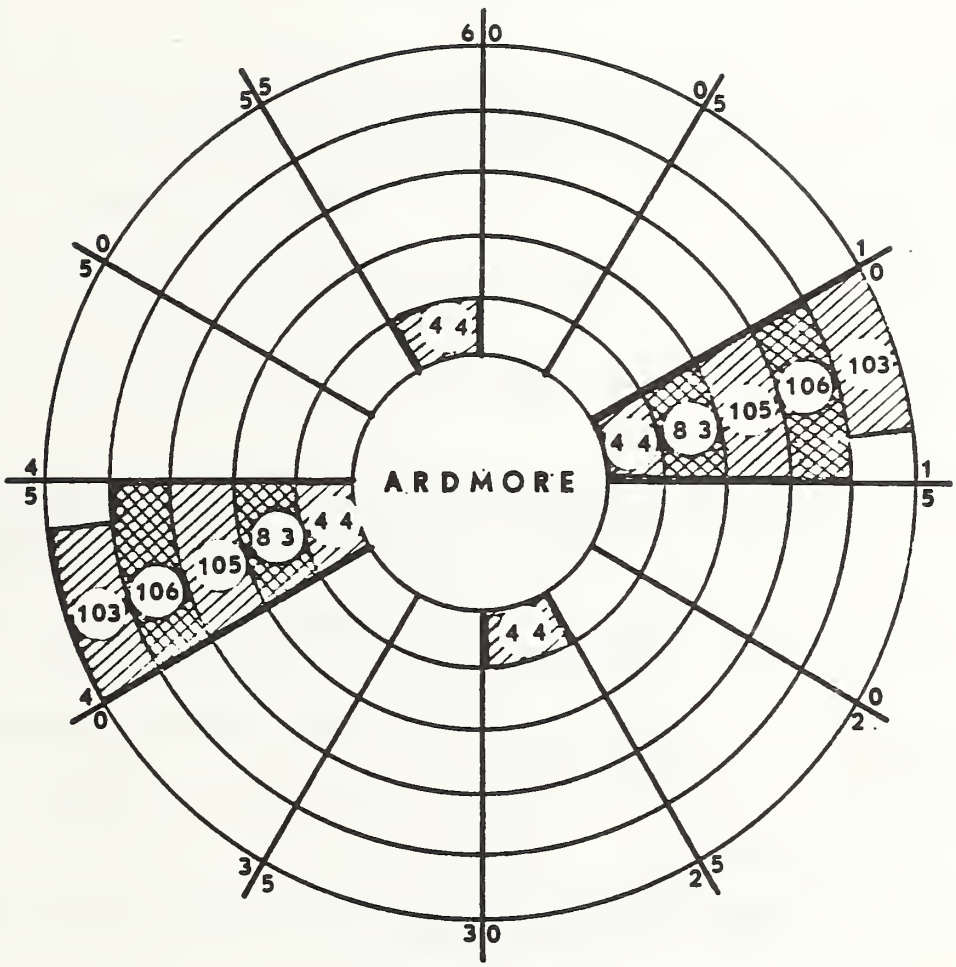


Figure 8.11 Ardmore transit center with fully synchronized schedules

a very modest increase in operating costs and one might expect that it would be easily offset and exceeded by additional revenues from newly attracted passengers. The increased level-of-service and passenger convenience would be additional and very significant gains.

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